FINAL REPORT

Assessment of Fuel Formulation Options for Maricopa County

for

State of Arizona
Department of Environmental Quality

performed under

Contract 97-0013AA

by

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EXECUTIVE SUMMARY

MathPro Inc. (prime contractor) and Air Improvement Resource, Inc. (sub-contractor) are pleased to submit this report to the Arizona Department of Environmental Quality (**ADEQ**), as the final work product of Task 1 under Contract 97-0013AA (August 9, 1996). The Scope of Work (SoW) for this task is shown in **Appendix A**.

We have prepared this report to support the work of the Fuels Subcommittee of the Arizona Air Quality Strategies Task Force (the Subcommittee). The report lays out the methodology, findings, and recommendations of our analysis of prospective gasoline formulations and standards aimed at decreasing vehicle emissions of volatile organic compounds (VOC) in Maricopa County in the Summer season (May 1 to September 30).

The report addresses six topics, each in its own section.

1. Proposed gasoline standards
2. The current gasoline supply situation in Maricopa County
3. Configuration and economics of the gasoline distribution system serving Maricopa County
4. Refining economics of the proposed gasoline standards
5. Estimated VOC and other emissions associated with the proposed gasoline standards
6. Assessment of the proposed gasoline standards

Technical Approach

We assessed six proposed gasoline standards in this study:

1. Federal RFG (Phase 1 now; Phase 2 starting in 2000) (**Phase 1 RFG**) and (**Phase 2 RFG**)

2. Federal RFG, with a waiver for $RVP \leq 7.0$ *psi* (**Phase 1 RFG & 7.0 RVP**)

3. California Phase 2 RFG (**California RFG**)

4. Conventional gasoline, with T50, T90, and sulfur control (**GEPAP**)
   $T50 \leq 220^{o}$ *F*; $T90 \leq 339^{o}$ *F*; *sulfur* ≤ 116 *ppm*

5. Conventional gasoline, with $RVP \leq 6.5$ *psi* (**Low RVP**)

6. Performance Standard: ? VOC Emissions $\geq$ 10% (**10% VOC Reduction**)

? NOx Emissions = 0%

The first five are specified in the SoW and are all *property-based* standards. We added the last one to introduce a *performance-based* standard into the set of options considered, as requested in the SoW.

Except for Options 1 and 2 (federal RFG), all of these gasolines -- including Option 3 (California Phase 2 RFG) -- would be *conventional gasolines* under the anti-dumping provisions of the federal RFG program.

The study had three primary elements: analysis of the *gasoline distribution system* serving Maricopa County; analysis of *refining economics*, with primary emphasis on the costs of producing the various fuel formulation options; and analysis of the changes in *vehicle emissions* associated with each of the fuel formulation options.

In the refining analysis, we considered three refining aggregates:

? **East** (denoting refineries in the West Texas/New Mexico refining center, supplying gasoline to Maricopa County by pipeline through El Paso and Tucson);

? **West** (denoting the Los Angeles refining center plus one refinery each from the Bakersfield and San Francisco refining centers, supplying gasoline to Maricopa County by pipeline from Los Angeles through Colton); and

? **Northwest** (denoting refineries in the Puget Sound refining center and, more generally, remote refineries (1) capable of producing conventional gasoline, California RFG, Maricopa County gasoline, or gasoline blendstocks and (2) situated to move gasoline or blendstocks to Los Angeles)

We aggregated the results associated with these refining aggregates to develop average incremental refining costs and average properties for the total Maricopa County gasoline pool, for each of the fuel formulation options. For this aggregation, we used weighting factors consistent with the sourcing of gasoline supplied to Maricopa County in 1995.

We conducted the emissions analysis using (1) the weighted average properties of the future Maricopa County gasoline pool, generated by the refining analysis for each fuel formulation option, and (2) the average properties of the baseline gasoline for the analysis: Maricopa County gasoline in the Summer 1996 season. We estimated the properties of this baseline gasoline using the Arizona Gasoline Quality Monitoring reports submitted by refineries producing gasoline meeting existing Maricopa County standards. The emissions analysis employed established, peer-reviewed models: the EPA MOBILE5 a model for estimating vehicle fleet emissions, the EPA Complex Model for certifying federal RFG, and the California Predictive Model for certifying California RFG.

Key Results and Findings

The key findings with respect to the gasoline distribution system are:

? The gasoline distribution system is now supplying to Maricopa County, in routine operations, special gasolines -- in particular, gasolines meeting Maricopa County standards, as opposed to State-wide (or Pima County) standards.

? The existing distribution system has the capability to deliver the required volumes of special Maricopa County gasolines meeting any of the proposed standards (or indeed other standards, whether property-based or performance-based).

? The differences between Maricopa County and State-wide gasoline standards lead to spill-over and local give-away of "excess quality" (described in Section 3.5) in Maricopa County and in other areas. We estimate the cost of quality give-away in current operations to be approximately:

Summer season	**0.2 ¢/gal**	**$ 3 MM/season**
Winter season	**0.4-0.6 ¢/gal**	**$ 6- 9 MM/season**
Year-round	**0.3-0.4 ¢/gal**	**$ 9-12 MM/year**

Quality give-away is a social cost, that is, a cost incurred by society as a whole. Allocation of the cost of quality give-away -- refiners vs. consumers, inside vs. outside Maricopa County -- is difficult, if not impossible, to determine.

? The estimated range of annual capital charges for the investments required to abate quality give-away is about $7-11 MM/year, roughly the same as the estimated range of annual costs of quality give-away (indicated above). That is, the distribution system as a whole appears close to having an economic incentive to reduce or eliminate excess quality in the system, independent of any new gasoline standards for Maricopa County.

? Should these investments be made, the incremental cost of quality give-away assignable to the new Maricopa County standard would be the *difference* between (1) the current costs of quality give-away and (2) the annual capital recovery charges for the investments to abate quality give-away. This difference is not significant relative to the refining and fuel economy costs associated with the various fuel formulation options.

The key findings with respect to refining economics and vehicle emissions are summarized in **Exhibit ES-1**.

Exhibit ES-1: Cost-Effectiveness, Refining and Mileage Costs and VOC, NOx and CO Emission Reductions, by Fuel Formulation Option – Summer Season

		Fuel Formulation Option						
	Baseline	Federal RFG			California		Low	10% VOC
Measure	Emissions	Phase 1	Phase 1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Cost-effectiveness ($M/ton of VOCs)								
1999								
Complex Model		$63	$28	$25	$41	$18	-	$18
Predictive Model		$34	$22	$23	$37	$15	-	$17
2010								
Complex Model		$215	$78	$63	$98	$33	-	$43
Predictive Model		$113	$62	$56	$73	$24	-	$36
Refining and Mileage Costs (¢/gal)								
Incremental Refining Cost		3.7	3.8	5.1	11.5	2.0	0.2	4.6
Cost of Mileage Loss*		3.7	3.7	4.2	5.8	0.2	-0.2	2.1
Total Unit Cost		**7.4**	**7.5**	**9.3**	**17.3**	**2.3**	**-0.0**	**6.7**
Maricopa County Cost ($M/day)**								
1999		$245	$247	$307	$571	$74	-	$223
2010		$474	$474	$571	$981	$105	-	$376
Vehicle Emission Reductions (tons/day)								
VOCs								
1999								
Complex Model	140.4	3.9	8.7	12.5	14.1	4.2	2.4	12.1
Predictive Model	140.5	7.2	11.0	13.3	15.5	5.0	0.5	12.9
2010								
Complex Model	100.1	2.2	6.1	9.0	10.0	3.2	2.2	8.8
Predictive Model	99.8	4.2	7.6	10.2	13.4	4.4	0.3	10.4
NOx								
1999								
Complex Model	96.6	0.3	0.2	2.0	8.2	1.3	-0.2	0.0
Predictive Model	96.2	1.1	1.1	2.8	8.8	2.6	-0.2	1.2
2010								
Complex Model	97.7	0.4	0.3	2.2	8.8	1.5	-0.2	0.1
Predictive Model	96.3	1.5	1.5	3.0	8.9	3.2	-0.1	1.2
CO								
1999	1048.5	108.8	118.6	143.3	198.3	44.5	20.4	38.6
2010	789.0	81.6	89.1	107.7	148.8	33.3	15.3	29.0

Note: All costs, emission reductions, and cost-effectiveness measures are for the summer season only.

* The cost of mileage loss is estimated as the percent loss in fuel economy times the summer retail price for gasoline (about $1.40/gallon), minus the Arizona State gasoline tax (18 ¢/gal), and plus the incremental refining cost of each fuel formulation option.

** Assumes gasoline sales in Maricopa County in 1999 and 2010 are 12% and 44% higher, respectively, than sales in 1995 of about 70,200 bbl/d.

Sources:

Costs and Mileage Loss: Exhibit 6.2

Emission Baselines and Reductions: Exhibits 5.6, 5.7, and 6.3.

Exhibit ES-1 shows the estimated cost effectiveness, in $ per ton of VOC emission reduction (**$/ton VOC**), of the fuel formulation options considered. The exhibit contains separate estimates of cost effectiveness for 1999 and 2010.

These estimates should be viewed as robust indicators of the relative costs and merits of the various fuel formulation options (not as precise assertions of costs or benefits). They offer a means of rank ordering of the various fuel formulation options, at least with respect to the technical and economic factors considered in this study.

The results summarized in Exhibit ES-1 indicate that

? The **GEPAP** and **Low RVP** options have favorable cost effectiveness values, but offer little in the way of VOC emission reductions.

? The federal RFG options, **Phase 1 RFG & 7.0 RVP** and **Phase 2 RFG**, and the **10% VOC Reduction** option offer the strongest combinations of VOC emission reductions and cost effectiveness -- before accounting for the possible neutralizing effects of the accompanying reduction in emissions of nitrogen oxides (NOx) associated with the federal RFG options.

? The **California RFG** option offers the largest VOC emission reduction, but with cost-effectiveness inferior to the federal RFG and 10% VOC reduction options -- again before accounting for the possible effects of the accompanying NOx reductions associated with California RFG.

? The choice of emission modeling methodology -- Complex Model vs. Complex/Predictive Models -- influences the magnitude of the estimated VOC emission reductions and the estimated cost effectiveness of the various fuel formulation options, but not their rank ordering with respect to these measures.

? The cost-effectiveness of each fuel formulation option decreases from 1999 to 2010. As time goes on, improvements in vehicle emission control technology and changes in the distribution of model years in the vehicle fleet progressively reduce engine exhaust emissions (with fuel properties constant). These trends reduce the magnitude of emissions reductions, in tons per day, that improvements in gasoline properties can yield.

? Carbon monoxide (CO) reductions could be equivalent to an additional 1-4 tons/day of VOC reductions, depending on the fuel formulation option. These estimated reductions follow from the CO emission reductions shown in Exhibit ES-1 and the accepted reactivity factor for CO as an ozone precursor (noted in Section 6.4). Fuel formulation options involving oxygenate blending show the largest reductions in CO emissions.

This last point indicates that clarifying the effect of CO emissions on ozone levels in Maricopa County in the UAM modeling work (along with the effect of NOx emissions) would sharpen future assessments of various fuel formulation options for ozone control.

The results of this study indicate little or no impact of the various fuel formulation options on areas of Arizona outside of Maricopa County.

> As noted above, the gasoline distribution system serving Maricopa County may now have (or be close to having) an economic incentive to abate the costs of spill-over and local quality give-away that the system now incurs. Any new gasoline standard for Maricopa County would increase that incentive.
>
> Moreover, the Subcommittee has adopted the position that, after adoption of a new gasoline standard for Maricopa County, refiners would produce Maricopa County gasoline to the new standard in a manner such that areas in Arizona outside Maricopa County would experience no decrease in the emissions performance of the gasoline that they received.

Finally, further analysis might identify one or more performance-based standards tailored to Maricopa County's requirements that would (1) yield substantial VOC emission reductions (with the desired change in NOx emissions) and (2) be less costly and more cost-effective than property-based standards or performance-based standards developed for other circumstances (e.g., Federal RFG and California RFG standards).

1. PROPOSED GASOLINE STANDARDS

In the SoW, the statement of **Task 1** (Identification of Fuels Formulations and Regulatory Options) calls for "investigat[ing] the range of options available for changing gasoline formulations that will reduce emissions of [VOC] during the summer months. ..."

This section specifies the options, or proposed gasoline standards, analyzed in this project.

1.1 Property-Based and Performance-Based Emissions Standards

One can define a proposed emissions standard for gasoline in two ways:

? *Property-based*, expressed as a set of limits on measurable physical properties of the regulated gasolines (e.g., RVP, sulfur content, distillation curve, etc.)

? *Performance-based*, expressed as a set of upper limits on the vehicle emissions of various species of pollutants produced by the regulated gasolines (e.g., VOC, NOx, and toxics)

The federal Phase 1 RFG program now incorporates a property-based standard, but shifts to a hybrid property- and performance-based standard in 1998. The California Phase 2 RFG program incorporates both kinds of standard, and allows refiners to choose between them.

The *property-based* standards for federal and California RFG cover eight gasoline properties:

Property	Units of Measure
RVP (Reid vapor pressure)	pounds per square inch (psi)
Aromatics content	vol. %
Benzene content	vol. %
Olefins content	vol. %
Oxygen content	wt. %
Sulfur content	wt. parts per million (ppm)
E200	% evaporated at 200^{o} F in a standard laboratory distillation
E300	% evaporated at 300^{o} F

Research indicates that these eight properties are the primary influences on vehicle emissions of volatile organic compounds (**VOC**), nitrogen oxides (**NOx**), toxics (and carbon monoxide (**CO**)) associated with a given gasoline.

In the refining industry, a gasoline's distillation properties usually are not reported as the E200 and E300 *percentages*, but rather as the T50 and T90 *temperatures*: respectively, the temperatures (in °F) at which 50 vol.% and 90 vol.% of the gasoline are evaporated. EPA derived two formulas for approximating E200 and E300 as functions of T50 and T90.

$$E200 = 147.91 - (0.49) * T50$$
$$E300 = 155.47 - (0.22) * T90$$

We used these formulas (1) to convert T50 and T90 values drawn from various surveys and reports into E200 and E300 values, for use with the Complex Model, and (2) where appropriate, to convert E200 and E300 values generated by our refinery LP model into T50 and T90 values, for presentation purposes and for input to the Predictive Model.

The *performance-based* standards for federal and California RFG involve use of mathematical models -- respectively, the Complex Model and the Predictive Model -- for certifying at the refinery that each batch of gasoline produced complies with specified emissions standards. These models express the quantities of VOC, NOx, and toxics emissions produced by a given gasoline blend as functions of the eight gasoline properties listed above. That is, in performance-based standards, these eight properties -- which we call the *CM properties* -- are inputs to mathematical models that estimate the environmental performance of gasoline, in terms of vehicle emissions of VOC, NOx, and toxics.

In addition to the CM properties, two other gasoline properties are of interest.

Driveability Index (DI) is a function of three temperatures in the standard laboratory distillation.[1] DI is of particular interest to vehicle manufacturers, who hold that a gasoline's DI is an indicator of its effects on vehicle driveability. In particular, vehicle manufacturers recommend that gasoline DI be controlled at 1200 or below.

Energy density (ED), expressed in BTU/gallon, is a measure of a gasoline's fuel economy (miles/gal.); the higher the ED, the higher the mileage (all else equal).)

Both property-based and performance-based standards can be imposed either on a per-gallon basis (*each* gallon must meet the standard) or an averaging basis (the average gallon must meet the standard).

Property-based standards are simpler to design and enforce. Performance-based standards allow refiners more operating flexibility in meeting a given level of emissions performance. Added flexibility usually translates into lower refining costs.

The proposed gasoline standards could be implemented as either property-based or performance-based standards. The latter approach, of course, would call for a regulatory structure including a

[1] $DI = 1.5*T10 + 3*T50 + T90$

mechanism for certifying the emissions performance of each batch of gasoline produced for Maricopa County. The certification mechanism would involve converting the CM properties of each batch of gasoline properties into estimated emissions reductions, by means of a mathematical model (e.g., EPA's Complex Model).

1.2 Proposed Formulations and Standards

We considered six proposed gasoline standards in this analysis:

1. Federal RFG (Phase 1 now; Phase 2 starting in 2000) (**Phase 1 RFG**) and (**Phase 2 RFG**)
2. Federal RFG, with a waiver for *RVP* $\leq$ *7.0 psi* (**Phase 1 RFG & 7.0 RVP**)
3. California Phase 2 RFG (**California RFG**)
4. Conventional gasoline, with T50, T90, and sulfur control (**GAPEP**)
   T50 $\leq$ *220*^{o} *F; T90* $\leq$ *339*^{o} *F; sulfur* $\leq$ *116 ppm*
5. Conventional gasoline, with *RVP* $\leq$ *6.5 psi* (**Low RVP**)
6. Performance Standard: ?) VOC Emissions $\geq$ 10% (**10% VOC Reduction**)
   ? NOx Emissions = 0%

The first five are specified in the SoW. We added the last one to introduce a pure performance-based standard into the set of options considered. (In later sections of the report we identify the options by means of the abbreviations shown above.)

Except for Options 1 and 2 (federal RFG), all of these gasolines -- including Option 3 (California Phase 2 RFG) -- would be *conventional gasolines* under the anti-dumping provisions of the federal RFG program. That is, for each refiner supplying Maricopa County, these gasolines would be treated (for emission control purposes) as part of the refiner's total non-RFGpool, whose average emissions of VOC and NOx must not exceed the refiner's baseline emissions.

Following is a brief discussion of the proposed gasoline standards.

1.2.1 Federal RFG

This option involves Arizona's opting-in to the federal RFG program (Phase 1 and Phase 2) for Maricopa County. The federal RFG program operates year-round and provides a federal enforcement mechanism. Federal RFG delivers reductions in VOC, NOx (in Phase 2), toxics, and CO emissions. The VOC and Phase 2 NOx reductions are summer-only; the toxics and CO emission reductions are year-round.

Exhibit 1.1: Summary of Federal Reformulated Gasoline Standards

Type of Standard	Simple Model			Complex Model					
				Phase 1			Phase 2		
		Averaging*			Averaging*			Averaging*	
	Per gal.	Standard	Min/Max	Per gal.	Standard	Min/Max	Per gal.	Standard	Min/Max
Performance-based									
VOCs (% reduction)									
Class B	-	-	-	35.1	36.6	32.6	27.5	29.0	25.0
Class C	-	-	-	15.6	17.1	13.1	25.9	27.4	23.4
NOx (% reduction)									
Summer	-	-	-	0.0	1.5	-2.5	5.5	6.8	3.0
Winter	-	-	-	0.0	1.5	-2.5	0.0	1.5	-2.5
Toxics (% reduction)	15.0	16.5	-	15.0	16.5	-	20.0	21.5	-
Property-based									
Oxygen (wt %)	2.0	2.1	1.5	2.0	2.1	1.5	2.0	2.1	1.5
Benzene (vol %)	1.00	0.95	1.30	1.00	0.95	1.30	1.00	0.95	1.30
RVP (psi)*									
Class B	7.2	7.1	7.4	-	-	-	-	-	-
Class C	8.1	8.0	8.3	-	-	-	-	-	-

* Averaging: year round for toxics, oxygen, and benzene; and summer only for VOCs, NOx, and RVP. Benzene and oxygen must be averaged within "covered areas." RVP and VOCs must be averaged within Class B and C areas. (Arizona is a Class B area.)

Note: VOC, NOx, & Toxics reductions and Oxygen content must be greater than or equal to the standards. RVP and Benzene content must be less than or equal to the standards.

Anit-dumping standard:

Simple model -- calculated annual average exhaust benzene emissions less than baseline; and sulfur, olefin, and T-90 less than 125% of baseline.

Complex model -- annual average exhaust toxics and NOx emissions less than the baseline.

Source: Final Rule for Reformulated and Conventional Gasoline, Regulations, pp 529-532 and pp 843-844.

Exhibit 1.1 provides a summary of the federal RFG standards. As the exhibit indicates, the federal Phase 2 RFG program involves both property-based standards (on benzene and oxygen content in RFG) and performance-based standards (on VOC, NOx, and toxics emissions for RFG and on NOx and toxics emissions for conventional gasolines). The Complex Model is the medium for certifying compliance with the performance-based standards.

Although federal RFG is a year-round program, we assessed it as a summer program only. That is, we estimated its costs and benefits only for the Summer gasoline season.

1.2.2 Federal RFG, with a waiver for *RVP $\leq$ 7.0 psi*

This option also involves Arizona's opting-in to the federal RFG program (Phase 1 and Phase 2), but with a waiver granted by EPA to maintain the current requirement of RVP $\leq$ 7 .0 psi for gasoline sold in Maricopa County in the Summer (ozone control) season.

The waiver would eliminate the temporary relaxation in RVP control in Maricopa County that otherwise would be associated with the federal RFG program.

> Through 1997, federal *Phase 1* RFG caps RVP at 7.2 psi (under *per gallon* compliance) or 7.1 psi (under *averaging* compliance). In 1998 and 1999, refiners may set RVP consistent with the VOC emission performance standard for Phase 1 RFG. We expect most refiners will control RVP to 7.0-7.2 psi in this period. Thus, the federal RFG option could involve a small relaxation of current RVP controls (in 1997 and possibly in 1998 and 1999). After 2000, refiners may set RVP consistent with the VOC emission performance standard for federal *Phase 2* federal RFG. We expect most refiners will control RVP to 6.7-6.8 psi in producing federal Phase 2 RFG.

1.2.3 California RFG (summer only)

This option calls for adopting California's property-based standard and/or its performance-based standard, along with the Predictive Model for California Phase 2 RFG, *but only for the Summer season.*

The California RFG program has standing in California, but not in other states. In California, "California RFG" is a year-round emissions reduction program. In Arizona, "California RFG" would be simply a low-emissions gasoline formulation. So, Arizona could adopt the California RFG formulation for ozone control in the Summer gasoline season only -- and that's how we defined this option.

1.2.4 Conventional gasoline, with T50, T90, and sulfur control

This option is mentioned in the Governor's Air Pollution Emergency Proclamation of July 17, 1996 (hence the abbreviation GAPEP). It involves modifying the current Maricopa County gasoline pool (i.e., conventional gasoline with RVP $\leq$ 7.0 psi) by imposing limits on the gasoline pool's average

- ? *distillation curve*, as characterized by *T50* $\leq$ *220^o F; T90* $\leq$ *339^o F;* and
- ? *sulfur content* $\leq$ *116 ppm* (parts per million, by weight).

The proposed values are close to the corresponding average properties of the Maricopa County gasoline pool in the 1995 Summer season.

In the Complex Model, (1) the distillation curve has a second-order influence on NOx and VOC emissions and (2) sulfur content is the primary determinant of NOx emissions and the third most important determinant of VOC emissions.

1.2.5 Conventional gasoline, with low RVP

This option, as we defined it, tightens the RVP standard from the current 7.0 psi to 6.5 psi.

In the Complex Model, RVP is the most important influence on *non-exhaust* emissions of VOC (i.e., running losses, hot soak, and diurnal emissions). High ambient temperatures in the Phoenix area make the local non-exhaust VOC emissions higher than in most of southern California and the southern federal RFG areas. At the same time, RVP reduction is (up to a point) among the least expensive of all gasoline property modifications aimed at emissions reductions. These factors suggest that tighter RVP control would be attractive.

However, the RVP of the Maricopa County gasoline pool is already so low (7.0 psi) that it can't be reduced by more than about 0.2 psi without violating an anti-dumping provision of the federal RFG program. An RVP reduction that small would not yield important VOC emissions benefits.

> The anti-dumping provision in question sets a hard lower limit of 6.4 psi on RVP. This limit applies to each batch of gasoline produced, and is measured and enforced at the refinery gate. The precision of the RVP test method is about 0.3 psi and that the pipeline specification for RVP is set at 0.1 psi below the applicable standard. These factors suggest that 6.8 psi is the lowest practical minimum for an RVP specification. At that specification, the average in-use RVP for the gasoline delivered to Maricopa County would be about 6.5 psi (vs. the current average RVP of 6.7 psi).

Hence, the 6.5 psi RVP specification that we set for this option is lower than the minimum for compliance with the federal anti-dumping provision cited above. We set the RVP at 6.5 psi simply for convenience; one can use the costs and emissions benefits of this option to estimate (by linear interpolation) the corresponding values for any RVP in the range *6.8 - 7.0 psi.*

1.2.6 Performance standard:) VOC Emissions $\geq$ 10% (with) NOx Emissions = 0%)

This option calls for reducing VOC emissions by 10%, as estimated by EPA's *Phase 2 Complex Model* (applicable starting in 2000), with respect to the VOC emissions of the average gasoline delivered to Maricopa County in the Summer of 1996 -- while maintaining NOx emissions at the level corresponding to this baseline gasoline. (The properties of the baseline gasoline are discussed in Section 2.)

Our analysis suggests that to meet this standard, refiners would likely control the RVP, T50, T90, and aromatics content of gasoline produced for Maricopa County (although, of course, they would be free to pursue other courses of action).

In the Complex Model, the distillation curve and aromatics content have second-order influences on VOC emissions. In particular, the higher the T50 and T90, the higher the VOC emissions (all else being equal). The nature of gasoline blending is such that T50 and T90 tend to increase with decreasing RVP, unless the refiner takes special measures to decouple these properties.

1.3 Suggested Fuel Formulations Not Considered

Time and budget constraints precluded our analyzing additional fuel formulation options. Nonetheless, other prospective options merit consideration and detailed analysis. Members of the Subcommittee suggested several such options.

1.3.1 1990 baseline gasoline with low RVP

This option calls for each refiner to produce gasoline for Maricopa County with (1) CM properties that are -- from an emissions standpoint -- equal to or better than the refiner's EPA baseline gasoline properties and (2) low RVP ($\leq$ 6.8 or 7.0 psi).

This rationale for this option is to preserve the (non-exhaust) VOC emission benefits of Maricopa County's existing low RVP program (discussed in Section 2.1.1) and augment them with additional (exhaust) VOC emission benefits. The latter would be achieved through explicit control of the other CM properties, at levels achieved in prior operations.

1.3.2 GAPEP gasoline, without sulfur control

This option is similar to the GAPEP option described in Section 1.2.4. It involves modifying the current Maricopa County gasoline pool (i.e., conventional gasoline with RVP $\leq$ 7.0 psi) by imposing limits on the gasoline pool's average *distillation curve -- T50 $\leq$ 220^o F and T90 $\leq$ 339^o F* -- but without the explicit sulfur control of the GAPEP option.

This option concentrates on VOC emission reductions, through control of RVP and distillation curve, without accompanying NOx emission reductions. As noted in Section 1.2.4, sulfur content is the primary determinant of NOx emissions, but only a secondary determinant of VOC emissions. Hence, eliminating the sulfur control element of the GAPEP option should preserve that option's VOC emission reductions, but without its NOx emission reductions.

1.3.3 GAPEP gasoline, with low RVP

This option combines the GAPEP and low RVP options, described in Section 1.2.4 and 1.2.5, respectively.

This option offers the VOC and NOx emission reductions of the GAPEP option plus the incremental VOC emission reduction available from tightening the RVP standard to 6.8 psi (from the current 7.0 psi).

1.4 More on Performance-Based Standards

As noted in Section 1.2, we extended the set of fuel formulation options to include a performance standard -- 10% VOC reduction; 0% NOx reduction (based on the Phase 2 Complex Model). We established this option to illuminate the pros and cons of possible performance-based standards (consistent with the SoW). It is an example of performance-based standards that could meet Maricopa County's emissions requirements.

1.4.1 Desirable attributes of performance-based standards

Performance-based standards are of interest because they offer refining flexibility that can (1) lead to lower refining costs than property-based standards, for any target level of emission reduction, and (2) dampen the effects on refining costs of changes in market conditions.

One can map any proposed property-based standard into a corresponding performance-based standard, by setting target VOC, NOx, toxics, and/or CO emission levels matching those estimated for the specified property-based standard.

For example, one could express the full set of proposed gasoline standards described in Section 1.2 in terms of VOC emissions performance. That would allow results of the refining analysis (described in Section 4) to be expressed as a *VOC reduction function* -- that is, a curve of VOC emissions reduction versus incremental refining and distribution costs, over the range of proposed gasoline standards considered.

Such a curve could be used to estimate the trade-off between incremental refining cost and VOC emission reduction. In turn, this trade-off estimation could help guide policy makers to the most cost-effective levels of VOC reduction. This concept applies not only to VOC but also to other vehicle emissions that play a significant role in ozone formation.

1.4.2 On regulatory issues

Analysis of the issues -- analytical, technical, policy, and regulatory -- associated with setting emissions standards is beyond the scope of this study. These issues include:

? What should the standards be, in terms of the emissions to be covered and the allowable levels for each?

For example, as discussed in Section 1.6, reducing NOx emissions in concert with VOC emissions might (or might not) have an adverse effect on ozone formation in the Maricopa County airshed. That is, reducing NOx emissions might offset some or all of the benefits of VOC reduction. So, a VOC emissions standard might have to be paired with either a NOx emissions standard or (at least) a formula relating VOC and NOx emissions performance in a way that reflected the *net* effect on ozone formation of simultaneous changes in the VOC emissions and NOx emissions performance of a gasoline formulation or gasoline pool.

? How shall compliance be measured?

Measuring compliance involves a standard of reference -- that is, a baseline gasoline (or gasolines) -- a compliance basis (e.g., per-gallon or averaging), and a uniform, accepted means of estimating the emissions performance of given batches or samples of gasoline with respect to the baseline. In the federal and California RFG programs, the Complex Model and the Predictive Model, respectively, fill the latter role.

? How shall compliance be monitored and enforced?

Monitoring and enforcement calls for systems and procedures for sampling, testing, reporting, and record-keeping -- involving refiners, the pipeline system, and other entities that handle gasoline downstream of the pipeline. These systems and procedures must satisfy not only regulatory requirements but also operational requirements, such as fungibility of gasoline throughout the distribution system.

? What regulatory resources and regulatory structure must Arizona put in place to monitor and enforce a performance standard?

Federal RFG is a federal program, with enforcement by EPA. The other fuel formulation options would require enforcement by Arizona.

? Will EPA approve a state-level performance standard?

At present, California is the only state with its own performance standard for gasoline.

All of these issues apply to both property-based and performance-based standards. Some are more acute for performance-based standards.

1.5 Seasonal Considerations

1.5.1 Consistency with existing gasoline standards for Maricopa County

In the *Summer* (ozone control) season (May 1 to September 30), Arizona restricts gasoline RVP to $\leq$ 7.0 psi in Maricopa County.

All but the federal RFG option would restrict summer RVP to $\leq$ 7.0 psi, the current level of RVP control in Maricopa county.

In the *Winter* (CO control) season (October 15 to March 31), Arizona requires that gasoline sold in Maricopa County contain oxygen.

All but the federal RFG options would leave the winter oxygenated fuel program unaffected. The federal RFG program is year-round. It sets a minimum oxygen concentration of 2.0 wt.%, except in those areas in which both the federal RFG and oxygenated fuel programs are active. In these areas, the federal RFG program calls for an oxygen concentration of 2.7 wt.% (regardless of the oxygenate used) in the Winter season.

1.5.2 Focus on the Summer season

Options 1 and 2 (involving federal RFG) would be year-round programs; the others would apply only during the Summer season.

Adopting the Federal RFG program only for the summer season might be possible. However, the continuing operation of the oxygenate program in the winter season means that the incremental costs of the RFG program in the winter season would be small. Thus, it makes sense to view Options 1 and 2 as year-round programs.

However, in analyzing the options, we assumed full recovery of all investments in refinery capital made for purpose of compliance. To that end, we used capital recovery factors in our refining analysis (discussed in Section 4) that allowed for capital recovery exclusively in the Summer season, the only season in which the incremental capital stock would be required.

1.6 Possible Effects on Ozone Formation of Changes in NOx Emissions

Both federal Phase 2 RFG and California RFG provide reductions in vehicle emissions of NOx (relative to baseline conventional gasoline). California RFG provides a larger NOx reduction than federal Phase 2 RFG.

We understand that NOx reduction might have an adverse effect on ozone formation in the Maricopa County airshed, which could offset some or all of the benefits of VOC reduction.

The sensitivity of ozone formation to NOx reductions is to be delineated in the urban airshed modeling (**UAM**) work, which is in progress at this writing. Results of the UAM work regarding the effects of NOx emissions on ozone formations should be incorporated in future efforts to formulate and analyze proposed gasoline standards.

2. CURRENT GASOLINE QUALITY IN MARICOPA COUNTY

This section summarizes (1) the existing gasoline standards in Arizona and (2) the indicated average quality (in terms of the CM properties) of the gasoline supplies to Maricopa County in the 1996 Summer season. These are elements of the baseline that we established for assessing the proposed gasoline standards.

2.1 Existing Gasoline Standards in Maricopa County and Elsewhere in Arizona

At present, essentially all gasoline consumed in Arizona conforms to one of two regulatory standards. We call these the *Maricopa County* standard and the *State-wide* standard. As its name implies, the State-wide standard applies to the entire state -- except for Maricopa County.

2.1.1 The Maricopa County standard

In the Summer (*ozone* control) season, gasoline RVP must be $\leq$ 7.0 psi -- 0.8 psi below the Federal Phase 2 RVP limit of 7.8 psi for ozone non-attainment areas in the southern U.S. The Summer season is May 1 to September 30.

In the Winter (*CO* control) season, gasoline RVP must be $\leq$ 9.0 psi, and gasoline must be *oxygenated*. The required oxygen concentration is 3.5 wt.% if *ethanol* is the oxygenate and 2.7 wt.% if an *ether* (MTBE, ETBE, or TAME) is the oxygenate. These oxygen concentrations correspond to 10 vol.% ethanol in the gasoline, 15 vol.% MTBE, and 17 vol.% ETBE or TAME. The Winter season is October 1 to March 31 for the RVP standard and October 15 to March 31 for the oxygenated gasoline program.

The 1 psi RVP waiver is *not* available for ethanol blending in Maricopa County.[2] Nonetheless, at present, ethanol is the oxygenate of choice for all of Maricopa County's gasoline suppliers.

2.1.2 The State-wide standard

In the Summer season, gasoline RVP must be in the range 9.0 psi to 11.5 psi, depending on the month and the location within the state, in accordance with the industry-standard ASTM

[2] When ethanol is blended into gasoline, it increases the RVP of the gasoline by about 1 psi. In an effort to stimulate the use of ethanol as a gasoline blendstock, the federal government grants a 1 psi RVP waiver to conventional gasoline blends that contain ethanol. That is, for such blends, the applicable RVP specification or standard is deemed to be 1 psi higher than its stated value. The federal RVP waiver does not apply to reformulated or oxygenated gasolines, but states may grant their own RVP waivers for oxygenated gasolines.

Exhibit 2.1: Average Gasoline Properties and Emissions
Maricopa County – Summmer 1990 – 1996

Property/ Emissions	AAMA Gasoline Survey					AGQM
	1990	1992	1994	1995	1996	1996
Property						
RVP	8.1	7.0	7.4	6.8	6.8	6.7
Oxygen	-	-	-	-	-	0.1
Aromatics	32.8	33.4	33.2	33.0	36.2	34.2
Benzene	2.1	2.2	1.5	1.1	1.1	not reported
Olefins	6.0	7.4	8.5	8.6	6.8	10.2
Sulfur	125	208	166	161	116	155
T10 (1)	133.7	141.0	139.9	145.6	145.7	*145.6*
T50	219.1	224.9	221.6	226.4	233.2	226.0
T90	339.5	343.0	341.1	337.0	342.1	333.2
E200 (2)	41.2	38.4	39.5	37.0	35.0	37.2
E300 (2)	78.5	77.3	78.2	78.2	76.2	79.9
DI (3)	1197	1229	1216	1234	1260	1229
Emissions (mg/mi) (4)						
VOCs: Exhaust	897.4	901.3	888.0	879.1	926.7	858.6
Non-exhaust	450.8	311.2	353.1	294.1	294.1	286.5
Total:	1348.2	1212.5	1241.1	1173.2	1220.8	1126.8
NOx	1233.9	1274.9	1260.4	1253.2	1223.2	1257.9

(1) T10 for AGQM is assumed to be equal to AAMA value for 1995.
(2) Estimated using distillation curves, rather than EPA formulas.
(3) DI = 1.5 * T10 +3 * T50 + T90
(4) Calculated using EPA's Phase 2 Complex Model.

Sources: 1990 - 1995: AAMA National Fuel Survey, Summer 1990, 1992, 1994, and1995, for Phoenix, AZ;
1996: State of Arizona Gasoline Quality Monitoring Reports

schedule for RVP. (The Summer RVP standard for Pima County is 9.0 psi.) The Summer season is April 1 to September 30.

Outside of Maricopa County, Arizona requires no ozone control programs in the Summer season. In the Winter season, gasoline RVP is restricted to various levels, ranging from 9.0 psi to 13.5 psi, again in accordance with the industry-standard ASTM schedule for RVP. The Winter season is October 1 to March 31.

The Winter season adds an important local complication to the State-wide standard. Gasoline in Pima County -- but not elsewhere in Arizona (except for Maricopa County) -- must be *oxygenated* for CO control. The required oxygen concentration is 1.8 - 3.5 wt.% if *ethanol* is the oxygenate and 1.8 - 2.7 wt.% if an *ether* is the oxygenate.

The 1 psi RVP waiver is available for ethanol blending in Pima County. At present, ethanol is the oxygenate of choice for all of Pima County's gasoline suppliers.

Outside of Maricopa and Pima Counties, Arizona requires no CO control programs in the Winter season.

2.1.3 Implications of the different standards

The differences between the Maricopa County and State-wide standards with respect to RVP and (in the winter) oxygen content add complexity to the production and distribution of gasoline for consumption in Arizona. In particular, the differences lead to a proliferation of gasoline classes tailored to specific markets (e.g., low RVP gasoline for Maricopa County and higher RVP gasoline for the rest of the state; oxygenated gasoline for Maricopa County and Pima County and conventional gasoline for the rest of the state, etc.). As discussed in Section 3, the proliferation of gasoline grades adds to the cost of gasoline production and distribution.

2.2 Emissions Properties of Maricopa County Gasoline: Summer 1996

2.2.1 Average CM properties: June, July, and August

Exhibit 2.1 shows (1) average CM properties (and the DI) of the Maricopa County gasoline pool for *Summer 1996*, drawn from the State of Arizona Gasoline Quality Monitoring Reports (AGQM reports) for June, July, and August 1996 and (2) average CM properties of the Maricopa County gasoline pool for Summer 1990, 1992, 1994, 1995, and 1996, drawn from the corresponding American Automobile Manufacturers Association (AAMA) National Fuel Surveys.

Exhibit 2.2: VOC and NOx Emissions for Maricopa County Gasoline, Sorted from Low to High, by Supplier June – August 1996

Supplier	VOC Emissions (g/mi)	VOC Emissions % from Average	Supplier	NOx Emissions (g/mi)	NOx Emissions % from Average
Ultramar, Inc.	1.07	-4%	Ultramar, Inc.	1.1	-15%
76 Products Co.	1.08	-3%	Mobil Oil Corp.	1.2	-8%
Chevron	1.09	-2%	ARCO Products Co.	1.2	-8%
ARCO Products Co.	1.09	-2%	Texaco Ref. & Mkt., Inc.	1.2	-8%
Border Ref. & Mkt Co.	1.09	-2%	76 Products Co.	1.2	-8%
Shell Odessa Refining Co.	1.10	-1%	Chevron	1.2	-8%
Mobil Oil Corp.	1.11	0%	Border Ref. & Mkt Co.	1.3	0%
Texaco Ref. & Mkt., Inc.	1.12	1%	Tosco Corp.	1.3	0%
Tosco Corp.	1.18	6%	Shell Odessa Refining Co.	1.4	8%
Navajo Refining Co.	1.20	8%	Navajo Refining Co.	1.4	8%
Average:	1.11	0%	Average:	1.3	0%

Note: Calculation of "% from average" based on rounded g/mi numbers.

Source: Derived from State of Arizona Gasoline Quality Monitoring Data, June - August 1996.

The AGQM reports are submitted to ADEQ by the refiners who produce gasoline to Maricopa County standards. The reports lay out the CM properties (as measured at the refinery) of each gasoline batch produced to Maricopa County standards. (Operation of the gasoline distribution system is such that some batches shown in the AGQM reports actually may be shipped to markets other than Maricopa County or sold at retail under different brands.)

The AGQM Reports program began with the Summer 1996 season. The prior year estimates are drawn from the corresponding AAMA National Fuel Surveys. AAMA survey data are readily available and widely cited. Other published surveys (e.g., those by Southwest Research Institute (SwRI) and Arizona's Department of Weights and Measures) also report gasoline quality data. Estimates of some CM properties in these other sources may differ from those in the AAMA surveys.

Differences in estimated average CM properties between 1995 and 1996 shown in Exhibit 2.1 reflect either (1) differences in survey methodologies or (2) changes in refining, gasoline blending, and gasoline supply operations. The latter could reflect the advent of the California Phase 2 RFG program (which took effect March 1, 1996) or efforts by refiners to upgrade the emissions performance of gasoline supplied to Maricopa County.

2.2.2 Indicated changes in vehicle emissions

Exhibit 2.1 indicates that this summer's Maricopa County gasoline has higher aromatics and olefins content, lower sulfur content, and higher E300 than last summer's gasoline. These CM properties translate, through the Complex Model, into the estimates of vehicle emissions shown in the bottom section of Exhibit 2.1. These calculated values indicate that the Summer 1996 gasoline pool yielded a reduction in exhaust VOC emissions and small reductions in non-exhaust VOC and NOx emissions.[3]

2.2.3 Variations in the emission performance of gasoline supplies

The CM properties shown in Exhibit 2.1 are average values, applicable to Maricopa County's total

[3] ADEQ's news release of August 30, 1996 reported larger decreases in VOC and NOx emissions from the gasoline batches covered in the June 1996 AGQM Reports submitted by the refiners supplying gasoline to Maricopa County. The decreases reported by ADEQ are relative to the individual refiners' *1990* baselines. (Between 1990 and 1995, EPA and Arizona imposed stringent new standards on gasoline volatility, which (as intended) reduced vehicle emissions of VOC.)

gasoline pool. These averages, of course, mask differences in CM properties (and emissions performance) of gasolines produced by the various refineries supplying Maricopa County. The differences are significant.

Exhibit 2.3: Average Emissions for Maricopa County Gasoline, by Refining Center
June – August 1996

Source of Supply	VOCs (mg/mi)			NOx
	Exhaust	Non-exhaust	Total	
East	850.9	279.6	1130.5	1351.9
West	816.3	286.5	1102.8	1180.1
Northwest	*	*	*	*
Total	840.3	286.5	1,126.8	1,256.4

* Not reported for reasons of confidentiality.

Source: Derived from State of Arizona Gasoline Quality Monitoring Data.

Exhibit 2.2 shows the distribution of the VOC and NOx emissions for each refiner that submitted AGQM reports for June, July, and August 1996. As Exhibit 2.2 indicates, the "cleanest" and "least clean" gasolines (from an emissions standpoint) supplied to Maricopa County differ in their VOC and NOx emissions by about 12% and 23%, respectively.

Some aspects of the emissions performance of gasolines supplied to Maricopa County depend on the geographic region of origin. As discussed in Sections 3 and 4, Maricopa County receives gasoline from a small set of refineries in Texas and New Mexico (referred to here as the East group) and from a larger set in Los Angeles and elsewhere on the West Coast (referred to here as the West group).

Exhibit 2.3 shows the emissions performance of Maricopa County's Summer 1996 gasoline pool, broken down into its East and West components. (We made these estimates by suitably aggregating data from the June, July, and August 1996 AGQM Reports.) Exhibit 2.3 indicates that (1) the East and West gasoline pools have comparable VOC emissions and (2) the West gasoline pool has significantly lower NOx emissions than the East pool. The differences in NOx emissions result mainly from differences in the sulfur content of the various gasolines. (With all other CM properties held constant, the higher the sulfur content, the higher the NOx emissions.)

These findings are consistent with the crude slates and the refining capabilities of the refineries in the East and West groups.

2.3 Baseline Gasoline for the Analysis: Maricopa County, Summer 1996

We set the baseline gasoline properties for this study to match the average CM properties of Maricopa County's gasoline pool in the 1996 Summer season, as defined by the AGQM reports. (See Exhibit 2.1).

? We selected Maricopa County's average 1996 Summer gasoline as the baseline because Maricopa County seeks to obtain Summer season gasoline with better emissions performance than the gasoline it received in the 1996 Summer season.

  Using baseline CM properties corresponding to a prior period or periods would have risked either mis-stating the emissions benefits of the proposed gasoline standards or complicating both the estimation and the explanation of the emissions benefits.

? We used the AGQM reports rather than the AAMA survey to define Maricopa County's average 1996 Summer gasoline because

  -- The AGQM reports provide detailed information on the CM properties of this gasoline pool, by refinery of origin. This detail enabled us to establish separate sets of baseline CM properties for the gasoline supplied to Maricopa County by the East refineries and the West refineries. Having separate sets of baseline CM properties for the East and West refineries was a key element of our methodology for the refining analysis (described in Section 4).

-- The AGQM reports were available when we undertook the analysis; the 1996 AAMA survey was not.

-- The AGQM reports permit calculation of volume-weighted average properties over the entire Summer season, for all gasoline produced to Maricopa County standards. The various surveys (e.g., AAMA, SwRI) sample gasoline actually sold at retail in Phoenix, but they have limited temporal and location coverage.

As Exhibit 2.1 indicates, one's estimate of the average CM properties for Maricopa County's Summer 1996 gasoline depends on one's choice of data source. Using the AAMA survey instead of the AGQM reports would have led to a different baseline gasoline than the one we used in the analysis. A different baseline gasoline would have registered a different set of baseline emissions in our emissions analysis. Different baseline emissions, in turn, would have changed the emissions reductions estimated in the analysis for the various fuel formulations options.

We consider the AGQM reports to be the most appropriate basis for establishing the baseline gasoline, but we recognize that reasonable people might disagree.

3. ANALYSIS OF THE GASOLINE DISTRIBUTION SYSTEM SERVING MARICOPA COUNTY

The gasoline distribution system serving Maricopa County, Pima County, and the rest of Arizona has five components. Starting at the pump and working upstream to the refinery, the five are:

? *retail outlets;*
? the *tank wagon* fleet;
? local *bulk terminals*, which handle gasoline and other refined products;
? the product *pipeline system*, which handles gasoline and other refined products; and
? the supplying *refineries*, and associated product movement and storage facilities.

The last three are relevant to this project. Their current operations form part of the baseline for assessing the proposed gasoline standards.

We discuss the refineries in Section 4. Here in Section 3, we delineate the pattern of gasoline consumption in Maricopa County, briefly discuss the bulk terminals, and then address the main topic of the section: the configuration and economics of the product pipeline system.

3.1 Pattern of Gasoline Consumption in Maricopa County and Adjacent Counties

Exhibit 3.1 shows Arizona's total gasoline consumption in 1993, 1994, and 1995, by season. Average consumption for the three-year period was about **124 M Bbl/day**, with negligible seasonal variation and annual growth of 3%-3.5% per year. growth. Average consumption in 1995 was about **130 M Bbl/day**.

Of this volume, approximately 83% was produced (at the refineries) as regular gasoline, < 1% as mid-grade, and 17% as premium. Additional mid-grade was produced for sale by secondary blending of premium and regular at the bulk terminals. We estimated these grade splits using data from two sources: the U.S. Department of Energy publication, *Petroleum Marketing Annual* (for 1994), and reports of shipment volumes for 1995 provided by Santa Fe Pacific Pipeline Partners (operator of the pipeline system that supplies Maricopa County).

Exhibit 3.2 shows Arizona's gasoline sales volume in 1995, which we have broken down by local source of supply and the counties they serve.

By "local source of supply" we mean the location of the bulk terminals (or in one instance, the refinery) that handle the gasoline volumes sold in a given county. For instance, the bulk terminals in Phoenix serve Maricopa, Coconino, Gila, and other counties; the bulk terminals in Tucson serve Pima, Santa Cruz, and other counties.

Exhibit 3.: Arizona Gasoline Consupmtion, by Season*
(M bbls/day)

Year	Distribution (%)		Daily Average
	Summer	Winter	
1993	121.0	122.2	121.1
1994	126.8	126.1	126.2
1995**	-	-	130.2

* Summer season is the period, May 1 through September 30.
Winter season is the period, October 1 through March 31.

** Seasonal consumption not reported because of a reporting error by the state that moves gasoline from the winter to the summer season.

Sources: Exhibits 3.3A, B, and C; and Federal Highway Stantistics, Federal Highway Administration, 1993 - 1995.

Exhibit 3.2: Estimated Arizona Gasoline Sales by Local Source of Supply and County, 1995
(barrels/day)

Local Source of Supply	County	Gasoline Sales
IN STATE:		
Phoenix		**86,900**
	Coconino	5,900
	Gila	1,700
	La Paz	1,200
	Maricopa	70,200
	Pinal	3,800
	Yavapai	4,100
Tucson		**27,800**
	Cochise	3,000
	Graham	700
	Greenlee	200
	Pima	22,500
	Santa Cruz	1,400
OUT-OF-STATE:		
California	Yuma	**4,200**
New Mexico		**5,600**
	Apache	1,800
	Navajo	3,800
Nevada	Mohave	**5,800**
Grand Total:		**130,200**

Source: Derived from Exhibits 3.1 and 3.3B.

To derive Exhibit 3.2, we assigned counties to supply sources based on (1) gasoline sales volumes by county obtained from the Arizona Department of Commerce; (2) information supplied by bulk terminal operators; and (3) the relative proximity of the counties to the local sources of supply.

Data supplied by Santa Fe Pacific Pipeline Partners indicate gasoline deliveries in 1995 of about **82.5 M Bbl/day** and **25.5 M Bbl/day** to bulk terminals in Phoenix and Tucson, respectively. These values are generally consistent with the allocations in Exhibit 3.2, which are based on county sales volumes.

From Exhibit 3.2, we see that

? Appoximately 88% of Arizona's gasoline volume flowed through terminals in Maricopa County (Phoenix) or Pima County (Tucson) in 1995;

? Approximately 81% of the gasoline flowing through terminals in Phoenix was consumed in Maricopa County; the remaining 21% flowed to adjacent counties; and

? Maricopa County and Pima County accounted for approximately 54% and 17%, respectively, of total gasoline sales in Arizona.

Finally, **Exhibits 3.3A, B, and C** (located at the end of this section) show the volumes of gasoline consumption, by county and by month, for 1993, 1994, and 1995, respectively. We obtained these data from the Arizona Department of Commerce (Office of Energy).

3.2 Bulk Terminals in Maricopa County

Bulk terminals are local distribution facilities for refined products. They receive shipments of refined products (e.g., by pipeline); provide tankage for product storage; handle finishing operations (e.g., additive addition, ethanol blending, mid-grade blending); and convey products to tank wagons for delivery to retail outlets.

Six bulk terminals in Phoenix handle gasoline: ARCO Products Co.; Chevron USA, Inc.; Santa Fe Pacific Pipelines; Texaco Refining & Marketing, Inc.; Unocal Corp.; and Wil-Jet. The Santa Fe Pacific Pipelines bulk terminal is the largest of the six; it handles bulk distribution for Mobil, Shell, and other companies. The terminals typically supply both proprietary tank wagons and jobbers that deliver outside of their service area or to different brand retail outlets.

The primary market area for bulk terminals in Phoenix is Maricopa County -- about 80 % of gasoline handled by these terminals is sold in Maricopa County. The remaining 20 % is sold in surrounding counties -- Coconimo, Gila, La Paz, Pinal, and Yavapai. Exhibit 3.2 shows estimated percentages of the gasoline handled by Phoenix bulk terminals that is sold at retail in each of these counties. (We did not study the terminals in the Tucson area.)

3.3 The Pipeline System Serving Maricopa County

One refined product pipeline system serves Phoenix and Tucson. It is owned and operated by Santa Fe Pacific Pipeline Partners, L.P (SFPP).

3.3.1 Configuration of the SFPP pipeline system

SFPP's South System delivers refined products to Phoenix, Tucson, and other destinations through two pipelines. The West line moves refined products from the Los Angeles Basin to Phoenix and on to Tucson. The East line moves refined products from El Paso to Tucson and on to Phoenix.

For purposes of this analysis, one may view the West line as a high capacity (24" and then 20") line from Watson (in the Los Angeles Basin) to Phoenix, with a smaller (6") line from Phoenix to Tucson. Similarly, the East line is a 12" and 8" looped line from El Paso to Tucson, with an 8" line from Tucson to Phoenix. By virtue of this configuration, both Phoenix and Tucson are served by both West and East refineries.

At Colton (in Southeastern California, near the border with Arizona), the West line has a connection with the Cal-Nev pipeline, which carries refined products (produced in the Los Angeles refining center) on to the Las Vegas market area. (Las Vegas gasoline is subject to standards that are essentially the same as Arizona's State-wide standards.)

In a letter to us (dated September 26, 1996), SFPP stated that

> ". . .the West line generally does not operate at full capacity. In the past several years, [the West line's segment between SFPP's Watson Station (in the Los Angeles Basin) and Colton Terminal] has operated at capacity for limited periods due to unusual circumstances and seasonal transitions. Unusual circumstances include instances when [refiners in the East group] have experienced operational difficulties and requested unusually large volumes be moved to Phoenix and/or Tucson from the Los Angeles area. Seasonal transitional periods (expecially the spring transition to low RVP [gasoline]) result in customers drawing down their inventories to turn the tanks to the new specification. After the tanks are turned, unusually large volumes may be moved in a brief period to replenish inventories.
>
> In the past several years, the [East] pipeline has not operated at capacity."

Exhibit 3.4 shows the average daily gasoline volumes delivered in 1995 by the West and East lines to Phoenix and Tucson terminals. About 72 % of gasoline supplied to Phoenix is from the

West line (28 % from the East line). About 88 % of gasoline moved through the West line is delivered in Phoenix, with the remaining 12 % going to Tucson. About 57 % of gasoline moved by the East line is delivered in Phoenix.

Exhibit 3.4: Pipeline Deliveries of Gasoline to Phoenix and Tucson, by Grade and Pipeline, 1995
(barrels/day)

Product/ Delivery Area	Pipeline		Total
	West	East	
Phoenix	**59,600**	**22,800**	**82,400**
Premium	11,500	2,600	14,100
Regular	48,100	20,200	68,300
Tucson	**8,200**	**17,300**	**25,500**
Premium	1,700	2,200	3,900
Regular	6,500	15,100	21,600
Phoenix & Tucson	**67,800**	**40,100**	**107,900**
Premium	13,200	4,800	18,000
Regular	54,600	35,300	89,900

Source: "Trunk Line Product Recap Report," Santa Fe Pacific Pipeline Partners, L.P., Products Movement Department, Dec. 1995.

Exhibit 3.5: Pipeline Flows of Gasoline and Percent Distribution of Gasoline Sales, by County, for Phoenix Bulk Terminals

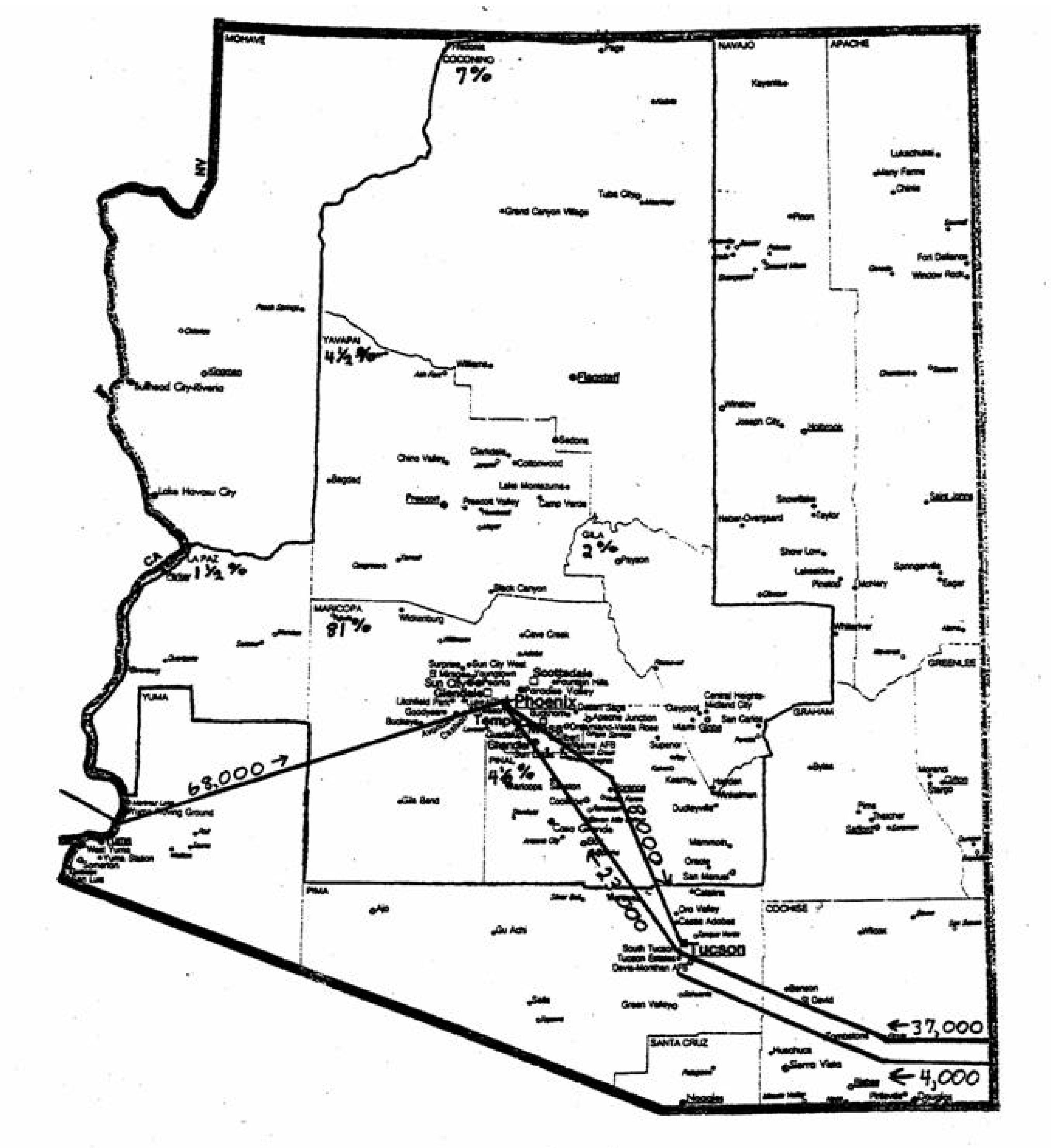


Exhibit 3.5 shows the location of the East and West pipelines and the average daily gasoline flows to Phoenix and Tucson terminals.

The tariffs for gasoline shipments in the South System, as January 26, 1996, are:

	¢/Bbl	¢/gal
? Los Angeles to Phoenix	126.2	3.00
? Los Angeles to Tucson	154.3	3.67
? El Paso to Tucson	73.0	1.74
? El Paso to Phoenix	101.0	2.40

Hence, for shipments to Phoenix, refiners in West Texas and New Mexico have a transportation cost advantage of about 0.6 ¢/gal relative to refiners in the Los Angeles refining center.

3.3.2 Capabilities of the SFPP pipeline system to handle multiple gasoline grades

As noted in Section 2.1.3, the differences between the Maricopa County and State-wide gasoline standards create the requirement for numerous gasoline grade classes, which must be produced and delivered to the appropriate locations.

SFPP reports that its South System has the following capabilities for handling gasoline grade classes. (Actual shipments depend on what refiners nominate for transportation through the pipeline.)

? The West line has the capability to transport up to six (6) grades of gasoline to Phoenix.

During the Winter season, the six grades are:

1. Sub-octane unleaded regular RVP 8.0 psi
2. Conventional unleaded regular RVP 8.0 psi
3. Conventional unleaded premium RVP 8.0 psi
4. Conventional unleaded regular RVP 9.0 psi
5. Conventional unleaded premium RVP 9.0 psi
6. Sub-octane unleaded regular RVP 9.0 psi

(The "sub-octane" unleaded regular grades are for ethanol blending.)

Grades 3 and 6 can be moved through break-out tankage in Phoenix to Tucson.

? The East line has the capability to transport up to three (3) grades of gasoline to Tucson and an additional four (4) grades of gasoline through Tucson to Phoenix.

During the Winter season, the grades delivered to terminals in Tucson are:

1. Sub-octane unleaded regular RVP per ASTM schedule
2. Conventional unleaded regular RVP per ASTM schedule
3. Conventional unleaded premium RVP per ASTM schedule

During the Winter season, the grades moved through break-out tankage in Tucson to Phoenix are:

1. Sub-octane unleaded regular RVP 8.0 psi
2. Conventional unleaded regular RVP 8.0 psi
3. Conventional unleaded premium RVP 8.0 psi
4. Conventional unleaded regular RVP 9.0 psi

The complexity of pipeline operations has increased as a result of the differences between the Maricopa County and State-wide standards.

3.4 The Proposed Longhorn Pipeline

The Longhorn Partners Pipeline is a proposed pipeline that would carry refined products from the U.S. Gulf Coast to El Paso, where it would link to the SFPP East pipeline. It would have an initial capacity of about 125 M Bbl/day, with a tariff in the range of 3.0 -3.5¢/gal.

If the Longhorn pipeline, or one comparable to it, were in operation, U.S. Gulf Coast refiners could move gasoline (and other refined products) to Maricopa County for about 5¢/gal less than they can now (via tanker shipments to Los Angeles and then through the SFPP West pipeline).

As discussed in Section 4.3, the entry of U.S. Gulf Coast refineries into the Maricopa County market would likely increase competition in the market. However, such entry(s) would be unlikely to change the overall pattern of incremental refining costs (at the refinery gate) and cost-benefit relationships among the proposed gasoline standards considered in this analysis.

3.5 "Excess Quality" in the Gasoline Distribution System

Setting new standards for Maricopa County gasoline in the Summer season could affect gasoline distribution (as contrasted with gasoline production) in two ways.

? It could increase the cost of "excess quality" -- that is, "spill-over" and the associated "give-away" of product quality. These cost increases could elicit changes in refining and distribution operations and/or investments in (1) additional blending facilities and tankage at the refineries, (2) additional break-out tanks along the pipeline, and (3) additional storage tanks at the bulk terminals.

? It could affect the volumes of gasoline available from current supply sources. For example, it could reduce the supply volumes from disadvantaged refineries.

We address the second issue in the refining analysis. This discussion focuses on the first issue.

3.5.1 The nature of excess quality, spill-over, and give-away

"Spill-over" denotes the distribution and sale of gasoline outside of the area for which it is intended. In this instance, it means selling Maricopa County gasoline outside the county (that is, where State-wide gasoline is called for). Spill-over is important in this situation because it leads to "give-away" of gasoline quality. Quality "give-away" denotes the sale of gasoline that meets more stringent quality standards -- and is therefore more costly to produce -- than is required where the gasoline is sold. In this instance, it means (1) selling Maricopa County gasoline outside of Maricopa County (i.e., where Pima County gasoline suffices) and (2) selling Winter season (oxygenated) gasoline in Maricopa County with octane higher than required.

Our analysis indicates that a significant level of spill-over currently exists in the distribution system serving Maricopa County. It is the result of (1) the need for the multiplicity of distinct gasoline grades, because of the differences in standards between Maricopa County and State-wide gasolines, (2) limitations on tankage and other facilities at some refineries and perhaps along the pipeline and at bulk terminals to handle the requisite number of grades (and the expense involved in expanding handling capabilities), and (3) the costs associated with moving and storing small volumes of material (e.g., premium gasoline).

In general, the Maricopa County gasoline standards, and the resulting spill-over, lead to these excess-quality situations:

? RVP give-away in the *Summer* season, because Maricopa County gasoline has an RVP standard 2.0 psi lower than State-wide gasoline in areas adjacent to Maricopa County (7.0 RVP vs. 9.0 RVP), and

? RVP give-away and octane give-away in *Winter* season, because (1) Maricopa County oxygenated gasoline has lower RVP than State-wide oxygenated gasoline and (2) ethanol blending (for oxygenated gasoline) at the bulk terminal contributes excess octane to the gasoline unless the ethanol is blended into a sub-octane gasoline produced for this purpose at the refinery. (This is the reason for the sub-octane grades shown above.)

In particular, quality give-away now occurs in the following ways:

? Summer

-- Most Phoenix bulk terminals carry *only* 7.0 RVP regular gasoline, rather than both 7.0 *and* 9.0 RVP regular gasolines. Thus, 7.0 RVP regular gasoline is sold in counties in the Phoenix market area that have a 9.0 RVP standard.

-- Phoenix bulk terminals carry only 7.0 RVP premium gasoline. Thus, all premium gasoline sold throughout the Phoenix market area is at 7.0 RVP, even though 9.0 RVP is allowed ex-Maricopa county.

-- A substantial portion of the gasoline delivered to Las Vegas via the Cal-Nev pipeline is 7.0 RVP, even though the Las Vegas standard is 9.0 RVP.

-- Much of the gasoline delivered to Tucson via the West line is at 7.0 RVP, even though Tucson and surrounding areas have a 9.0 RVP standard.

-- Typically, a small portion of the gasoline delivered to Tucson via the East line meets the 7.0 RVP standard.

? Winter

-- Most Phoenix bulk terminals carry only 8.0 RVP, 87 octane regular gasoline, rather than carrying both an 8.0 RVP, sub-octane gasoline -- for ethanol blending to Maricopa County's oxygenated gasoline -- *and* a high RVP, 87 octane regular gasoline for sale outside of Maricopa County. This leads to (1) octane give-away associated with most oxygenated regular gasoline sold in Maricopa county and (2) RVP give-away associated with most conventional regular gasoline sold outside of Maricopa county (but within the Phoenix distribution area).

-- Phoenix bulk terminals only carry 8.0 RVP premium gasoline. This leads to RVP give-away associated with all premium gasoline sold outside of Maricopa county.

-- Much of the gasoline delivered to Tucson via the West line is 8.0 RVP, even though Tucson and surrounding areas have more stringent RVP standards.

-- A portion of the gasoline delivered to Tucson via the East line meets the 8.0 RVP standard.

We understand that two companies -- ARCO Products and Texaco Refining & Marketing -- have taken the necessary steps (in refining and distribution) to minimize excess quality in their supplies to the Phoenix and Tucson areas. Their supplies constitute approximately 25% of the gasoline volume in the Phoenix and Tucson market areas. Other suppliers, for their own reasons, have not taken comparable steps.

3.5.2 The economics of excess quality

We estimate the total cost of excess quality in Arizona and other areas supplied through the SFPP South System to be about **$9-12 MM per year** -- about $3 MM for the Summer season and about $6-9 MM per year for the Winter season. These values correspond to about 0.2¢/gal for Summer gasoline and 0.4-0.6¢/gal for Winter gasoline.
Our estimates reflect the operational factors listed above and our assumption that ARCO Products and Texaco Refining & Marketing are not subject to them.

Exhibit 3.6 shows the details of our estimate, including the different kinds of excess quality give-away involved, by season, and the estimated unit marginal cost of the gasoline properties involved (octane and RVP).

Exhibit 3.6 indicates that the primary causes of the large cost in the Winter season are octane give-away in Maricopa County and RVP give-away outside of Maricopa County (but in the Phoenix distribution area). As the exhibit shows, we set the marginal cost of octane (MCO) at 0.6 cents per octane-barrel. Some members of the Subcommittee suggested that MCO could be lower than that in the Winter season. Accordingly, we repeated the calculation shown in Exhibit 3.6, but with MCO set at 0.2 cents per octane-barrel in the Winter season. This change reduced the computed cost of excess quality give-away by about $3 MM per year, or about 0.2¢/gal, for the Winter season. So, our estimated range of **$9-12 MM per year** for the cost of excess quality give-away corresponds to a range of 0.2-0.6 cents per octane-barrel for the marginal cost of octane in the Winter season.

In economic terms, excess quality is a social cost, incurred by society as a whole. The allocation of these costs -- refiners vs. consumers, inside vs. outside Maricopa County -- is difficult to assess. However, the gasoline distribution system as a whole has a financial interest in minimizing the extent of quality give-away, where practical.

3.5.3 Estimating the cost of excess quality for proposed gasoline standards

In principle, the cost of excess quality in Arizona is a function of the difference in total refining and distribution cost between Maricopa County gasoline and State-wide gasoline. Any new gasoline standard adopted for Maricopa County would likely increase this difference -- and therefore increase correspondingly both the social cost of the quality give-away and the economic incentives to reduce or eliminate it. This line of reasoning suggests that at some "cross-over point" (in terms of total cost of gasoline supply), the various players in the distribution system would have an economic incentive to invest capital and/or incur added operating costs to reduce or eliminate quality give-away.

Eliminating excess quality would entail the full segregation of Maricopa County gasolines, (regular and premium) from the refinery to the rack. Achieving full segregation would require investment (e.g., additional tankage, blending facilities, and inventory) and operational changes at the refinery, pipeline, and bulk terminal levels. The aggregate annual capital charges and incremental operating costs (if any) would be less than the total cost of the give-away that they were intended to abate. In other words, these costs would set an upper limit, or cap, on the cost of excess quality. The magnitude of the cap would be independent of the difference in total refining and distribution cost between Maricopa County and State-wide gasoline.

Exhibit 3.6: Estimated Cost of Excess Gasoline Quality in Arizona With Maricopa County Gasoline Standards

Season/ Area	Type of Spillover	Total Gasoline Volume (bbl/d)	Percent Affected (%)	Adjust. for Arco & Texaco (%)	Length of Program (days)	Affected Gasoline Volume (M bbl)	Per Gallon Cost Differential (¢)	Estimated Annual Cost ($ M)
Summer								3,100
Phoenix:	RVP giveaway, regular grade ex. Maricopa County	68,000	20%	25%	153	1,561	1.5	1,000
	RVP giveaway, premium grade ex. Maricopa County	14,000	20%		153	428	1.5	300
Tucson	West Line 7.0 RVP deliveries	8,200	33%		153	414	1.5	300
	East Line 7.0 RVP deliveries	17,300	5%		153	132	1.5	100
Yuma	West Line 7.0 RVP deliveries	5,000	100%		153	765	1.5	500
Nevada	West Line 7.0 RVP deliveries	40,000	23%		153	1,408	1.5	900
Winter								8,900
Phoenix:	Octane giveaway, regular grade in Maricopa County	68,000	80%	25%	180	7,344	1.68	5,200
	RVP giveaway, regular grade ex. Maricopa County	68,000	20%	25%	180	1,836	1.95	1,500
	RVP giveaway, premium grade ex. Maricopa County	14,000	20%		180	504	1.95	400
Tucson	West Line 8.0 RVP deliveries	8,200	63%		180	930	1.95	800
	East Line 8.0 RVP deliveries	17,300	15%		180	467	1.95	400
Yuma	West Line 8.0 RVP deliveries	5,000	85%		180	765	1.95	600
Total								12,000

Note: Average RVP for winter months, ex-Maricopa County is about 11.9 psi.

Assumptions: Marginal cost of RVP: summer -- 0.75 ¢/psi-gal, winter -- 0.50 ¢/psi-gal; octane giveaway: 2.8 numbers; and marginal cost of octane: 0.60 ¢/octane number-gallon.

Exhibit 3.7: Estimate of Investment Required to Eliminate Gasoline Quality Give-Away

Type of Cost	Lower Bound	Upper Bound
Capital Investment ($MM)	**28**	**45**
Refinery	20	35
Pipeline	5	5
Bulk Terminal	3	5
Capital Recovery Charge ($MM/year)*	**7**	**11**

* Calculated using a capital recovery rate of 25% for a required real, after-tax rate of return of 15%.

Exhibit 3.7 shows our estimate of the cap, expressed as a range of annual capital recovery charges, which in turn corresponds to a range of system-wide capital investment. As the exhibit indicates, we estimate the cap to be about **$7 - $11 MM/year**.

In developing this estimate, we assumed that the distribution system as a whole could achieve full segregation of Maricopa County gasolines through appropriate capital investment, with no significant increase in annual operating costs (other than capital recovery). We obtained, from various refining companies and from SFPP, rough estimates of the capital investments they would have to make to fully segregate Maricopa County gasolines. Using these rough estimates, we estimated the approximate range of total capital investment, system-wide, required to achieve full segregation of Maricopa County gasolines (both regular and premium) -- and thereby eliminate quality give-away.

A significant portion of the estimated capital investment is allocated to segregation of premium gasolines, which constitute only about 17% of the gasoline volume in Maricopa County (and a comparable fraction in near-by areas). That is, the economic incentive for segregating regular gasolines only is stronger than our estimate suggests.

Together, Exhibits 3.6 and 3.7 indicate that

? The current cost of excess quality is in the same range of magnitude as the cap on that cost (as defined above).

  That is, the distribution system as a whole appears close to having (or may already have) the economic incentive to reduce or eliminate excess quality in the distribution system.

? Each 1¢/gal increase in the incremental cost of gasoline production in the Summer season (the applicable season for the fuel formulation options) would increase the cost of excess quality give-away by about **$2 MM per year**.

  For example, if a new Maricopa County gasoline standard were to increase the incremental cost of Maricopa County gasoline by 5¢/gal (relative to the cost of State-wide gasoline), the cost of excess quality in the area of interest would roughly double.

The higher the incremental refining cost associated with a given fuel formulation option, the more likely that the adoption of that fuel formulation option would trigger investments to reduce or eliminate quality give-away.

If such investments were made, a pro-rata portion of their annual capital charges should be added to the incremental cost of the fuel formulation option in question. If such investments were not made, the incremental give-away costs should be added to the cost of the fuel formulation option.

Exhibit 3.3A: Arizona Monthly Gasoline Consumption, by County, 1993
(million gallons)

County	Jan.	Feb	March	April	May	June	July	August	Sept	Oct	Nov.	Dec	Total
						Month							
APACHE	2.89	1.58	1.49	1.41	2.17	1.57	2.34	2.02	2.46	2.35	2.18	1.82	24.27
COCHISE	3.01	3.59	2.35	3.79	3.48	3.63	3.46	3.57	3.69	3.46	3.52	3.99	41.54
COCONINO	5.75	4.71	5.26	5.95	6.86	5.84	7.80	8.53	8.76	7.96	7.39	5.92	80.73
GILA	1.36	1.78	1.62	1.97	2.06	2.20	2.09	2.26	2.27	2.07	1.94	1.95	24.09
GRAHAM	0.91	0.80	0.61	0.86	0.84	0.91	0.84	0.82	0.88	0.91	0.94	0.87	10.19
GREENLEE	0.34	0.32	0.24	0.34	0.30	0.33	0.33	0.44	0.43	0.35	0.33	0.38	4.12
LA PAZ	3.15	2.83	1.61	2.01	1.85	2.00	1.68	1.61	2.19	1.09	1.10	1.42	22.54
MARICOPA	87.17	83.34	78.52	92.06	86.95	82.55	76.93	79.44	79.31	79.49	84.73	85.42	995.92
MOHAVE	6.66	6.08	5.48	11.26	7.43	7.28	12.28	7.29	7.97	7.23	7.36	6.94	93.27
NAVAJO	3.81	3.26	3.06	5.37	4.18	4.25	5.11	5.31	5.38	5.04	4.54	4.33	53.64
PIMA	28.78	23.10	24.67	28.18	27.99	28.05	26.13	27.57	27.45	27.87	28.24	28.07	326.11
PINAL	4.56	4.56	4.65	5.21	4.50	4.16	4.03	4.01	4.03	3.87	4.36	4.38	52.31
SANTA CRUZ	1.51	1.44	1.19	1.56	1.50	1.54	1.41	1.39	1.45	1.44	1.41	1.66	17.50
YAVAPAI	4.74	3.76	4.30	4.28	4.76	4.75	5.00	4.89	4.97	4.39	4.93	4.76	55.55
YUMA	6.10	6.22	6.08	6.23	4.93	4.82	4.51	4.74	4.49	5.49	4.47	5.74	63.83
Total	161.23	147.38	141.14	170.18	158.72	53.90	153.94	153.91	155.74	153.00	157.44	157.64	1865.61

Source: Arizona Office of Energy, Department of Commerce.

Exhibit 3.3B: Arizona Monthly Gasoline Consumption, by county 1994
(million gallons)

County	Month												Total
	Jan.	Feb	March	April	May	June	July	August	Sept	Oct	Nov.	Dec	
APACHE	2.24	2.15	1.09	2.32	2.40	2.44	2.32	2.62	2.61	2.43	1.94	1.88	26.43
COCHISE	3.83	3.72	3.54	3.94	3.73	3.71	3.54	3.49	3.67	3.60	3.60	3.75	44.13
COCONINO	6.56	5.69	5.47	7.07	7.10	7.86	8.81	9.53	9.15	8.21	5.75	6.36	87.55
GILA	1.80	1.78	1.72	2.01	2.01	2.25	2.32	2.38	2.45	2.15	1.64	2.07	24.59
GRAHAM	0.89	0.80	0.79	0.91	0.88	0.90	0.90	0.88	0.95	0.92	0.83	0.82	10.47
GREENLEE	0.31	0.31	0.26	0.24	0.23	0.21	0.26	0.23	0.26	0.25	0.26	0.24	3.06
LA PAZ	1.56	1.96	1.66	1.63	1.45	1.58	1.38	1.52	1.43	1.37	1.36	1.62	18.52
MARICOPA	90.43	86.94	86.11	94.46	89.42	87.76	84.84	83.47	87.17	85.43	82.42	86.88	1045.33
MOHAVE	7.22	7.55	7.18	7.99	7.81	7.88	7.67	8.08	7.93	6.95	4.83	5.84	86.93
NAVAJO	4.39	3.89	3.31	4.51	4.46	5.03	5.03	5.88	5.47	5.56	3.85	4.51	55.89
PIMA	29.86	28.56	28.04	30.27	28.95	28.90	25.72	26.94	28.17	27.30	25.83	26.64	335.17
PINAL	5.09	4.82	5.30	5.73	4.71	4.61	4.31	4.27	4.32	4.31	4.41	4.78	56.66
SANTA CRUZ	1.91	1.81	1.63	1.88	1.70	1.80	1.62	1.62	1.72	1.38	1.72	1.64	20.42
YAVAPAI	4.86	4.42	4.42	4.72	5.21	5.16	5.01	5.75	5.76	5.69	4.05	5.52	60.57
YUMA	6.22	6.42	5.17	6.62	5.14	3.87	4.66	4.71	4.67	4.73	4.08	5.82	62.11
Total	167.17	160.81	155.68	171.12	165.18	163.96	158.38	161.38	165.73	160.28	146.57	158.37	1937.82

Source: Arizona Office of Energy, Department of Commerce.

Exhibit 3.3C: Arizona Monthly Gasoline Consumption, by County, 1995
(million gallons)

County	Month												Total
	Jan.	Feb	March	April	May	June	July	August	Sept	Oct	Nov.	Dec	
APACHE	2.10	2.63	1.53	2.01	2.21	2.50	2.51	2.46	2.67	2.48	2.45	1.76	27.31
COCHISE	4.13	2.48	3.43	4.04	3.94	4.11	3.86	3.94	3.76	3.81	3.96	3.24	44.71
COCONINO	6.36	5.68	5.41	6.93	7.18	8.31	8.89	9.71	9.12	8.46	7.99	6.66	90.70
GILA	2.01	1.80	1.65	2.16	2.18	2.36	2.34	2.51	2.25	2.26	2.20	1.79	25.53
GRAHAM	0.91	0.81	0.66	0.98	0.93	0.95	0.96	0.95	0.96	0.91	0.96	0.82	10.80
GREENLEE	0.20	0.25	0.24	0.26	0.28	0.28	0.28	0.29	0.38	0.50	0.28	0.23	3.47
LA PAZ	1.73	1.78	1.79	1.78	1.75	1.75	1.61	2.20	1.36	1.52	2.72	1.43	21.43
MARICOPA	90.51	63.12	33.90	93.86	88.78	89.47	86.68	85.70	89.59	85.76	93.28	92.17	992.82
MOHAVE	6.89	3.98	4.43	7.48	7.71	7.99	7.86	8.29	7.74	7.39	7.23	6.16	83.15
NAVAJO	4.29	3.73	3.56	4.21	4.48	5.13	5.25	5.65	5.83	4.87	5.01	4.38	56.40
PIMA	28.77	20.69	16.63	29.54	27.65	29.01	27.64	27.09	28.62	28.24	29.25	27.58	320.70
PINAL	5.25	4.76	4.28	5.62	5.07	4.78	4.68	4.69	4.62	4.53	4.85	4.52	57.66
SANTA CRUZ	1.92	1.52	1.27	1.61	1.62	1.66	1.56	1.54	1.60	1.43	1.44	1.02	18.22
YAVAPAI	5.19	4.15	4.79	5.53	5.68	5.62	5.91	6.02	5.23	6.77	6.08	4.90	65.88
YUMA	6.55	6.64	5.90	6.12	5.29	4.94	4.83	4.83	5.62	3.75	5.49	5.39	65.36
Total	166.80	124.02	89.48	172.15	164.74	168.87	164.86	165.88	169.36	162.70	173.21	162.06	1884.14

Source: Arizona Office of Energy, Department of Commerce.

Note: Gasoline sales not included in reported sales for February and March of 1995 were allocated by Arizona across other months.

4. ANALYSIS OF THE REFINING ECONOMICS OF THE PROPOSED GASOLINE STANDARDS

In the SoW, the statement of **Task 3** (Technical and Economic Analysis of Gasoline Production) calls for "estimat[ing] the feasibility and economic impacts of each [fuel formulation] option identified in Task 1. . .". This is the task that people usually call "refining analysis".

This section lays out our method for conducting the refining analysis. It covers six topics:

1. The mathematical modeling technique (linear programming) used for the refining analysis
2. The nature of refining analysis
3. Grouping the refineries of interest into regional refining aggregates
4. Representing the regional refining aggregates as "notional" refineries
5. Primary steps in the analysis
6. Key assumptions and analytical issues

4.1 Linear Programming: the Modeling Technique for Analyzing Refining Operations

Assessing the prospective impacts of the various proposed gasoline standards on the economics of gasoline production and on associated regional issues calls for engineering, or *techno-economic*, analysis of the refineries that produce gasoline supplied to Maricopa County.

The method of choice for conducting techno-economic analysis of refining operations is formal, computer-based modeling, employing a *refinery LP model*.

> LP stands for *linear programming*, a widely-used mathematical technique for optimization -- that is, for finding the best solution (in an economic sense) to complex problems involving the allocation of scarce resources across many competing activities. In refining analysis, the scarce resources are the production facilities of the refineries of interest and the competing activities are the various processing operations in the refineries.

Refining companies use in-house, custom-configured LP models of their own refineries for tactical and operations planning. Government agencies (e.g., EPA) and private sector organizations use generalized refinery LP models (that can be adapted to represent various refineries or refinery groupings) to estimate the effects on refining economics of proposed fuel standards or regulations.

With a refinery LP model, experienced analysts can simulate how a refinery or group of refineries would operate -- on an average day in a specified time period -- to produce specified products, such as the various fuel formulation options, at minimum cost. These simulations yield not only descriptions of prospective refinery operations but also estimates of the magnitude of the associated operating costs and the capital investment requirements (if any) for new or upgraded processing capacity.

For this project, we are using our proprietary generalized refinery LP modeling system, called **ARMS**. We developed ARMS independently and have used it many studies for clients in the public and private sectors. (**Appendix B** provides a brief overview of ARMS.)

4.2 The Nature of Refining Analysis

Refining analysis employing a refinery LP model yields three kinds of results in connection with a proposed regulation, such as a proposed new gasoline standard:

? estimates of *incremental refining costs* associated with the proposed standard;

? estimates of *capital investment requirements* and *operational changes* induced by the proposed standard; and

? estimates of the *properties* of the gasolines produced, for calculating emissions and other kinds of performance (e.g., fuel economy).

This family of results allows estimation of the total social cost of a proposed standard and allows rank-ordering a group of proposed standards by their total cost (or by their emissions levels). It also provides an indication of economic driving forces that could lead to changes in retail prices -- absent any changes in market structure.

By its nature, refining analysis cannot shed light on how the structure of the Maricopa County market or the pattern of gasoline supplies to Maricopa County would be likely to change -- either independent of or as a result of new gasoline standard adopted for the County. Such changes are driven not only by refining techno-economics (the object of refining analysis) but also by the situations in other gasoline markets and other refining centers throughout the U.S. and by business decisions taken by various refiners. These factors, though important to Maricopa County citizens, are beyond the scope of this analysis.

4.3 Specification of Three Regional Refining Aggregates for Analysis

4.3.1 Refineries represented in the analysis

At least ten refineries now produce gasoline for supply to Maricopa County under existing fuels programs. Another five to ten refineries are situated such that they could, under suitable circumstances, produce gasoline for supply to Maricopa County.

In particular, as mentioned in Section 2.2.3, two groups of refiners supply gasoline (and other refined products) to Maricopa County. The refiners that make up these groups are:

	Refiner	Refinery Locations
? West		
	76 Products Co./Unocal	Los Angeles, CA
	ARCO Products	Los Angeles, CA; Ferndale, WA
	Chevron Products Co.	El Segundo, CA; Richmond, CA
	Mobil Oil Corp.	Torrance, CA
	Texaco Ref. & Mkting., Inc.	Wilmington, CA; Bakersfield, CA; Anacortes, WA
	Tosco Corp.	Martinez, CA; Ferndale, WA
	Ultramar, Inc.	Wilmington, CA
? East		
	Shell Odessa Refining Co.	Odessa, TX
	Chevron Products Co.	El Paso, TX
	Navajo Refining Co.	Artesia, NM

With this many refineries, analyzing each individual refinery would risk yielding more numbers than insight, especially for making policy recommendations. Moreover, analysis of each individual refinery was not possible under the project's timetable and budget.

Therefore, for this analysis, we grouped the refineries of interest into three (3) regional refining aggregates:

? **East** (representing refineries in the West Texas/New Mexico refining center), supplying gasoline to Maricopa County via the SFPP East pipeline (El Paso to Phoenix, via Tucson)

-- Shell Odessa Refining Co.	Odessa, TX
-- Chevron U.S.A. Products Co.	El Paso, TX
-- Navajo Refining Co.	Artesia, NM

? **West** (representing the Los Angeles refining center plus one refinery each from the Bakersfield and San Francisco refining centers), supplying gasoline to Maricopa County via the SFPP West pipeline (Los Angeles to Phoenix, via Colton)

-- 76 Products Co./Unocal	Los Angeles, CA
-- ARCO Products	Los Angeles, CA
-- Chevron U.S.A. Products Co.	El Segundo, CA
-- Mobil Oil Corp.	Torrance, CA

--	Texaco Ref. & Mkting., Inc.	Wilmington, CA
--	Texaco Ref. & Mkting., Inc.	Bakersfield, CA
--	Tosco Corp.	Martinez, CA
--	Ultramar, Inc.	Wilmington, CA

? **Northwest** (representing refineries in the Puget Sound refining center), supplying gasoline to Maricopa County via marine tanker movements to Los Angeles and then the Santa Fe Pacific West pipeline.

--	ARCO Products	Ferndale, WA
--	Shell Oil Products	Anacortes, WA
--	Texaco Ref. & Mkting., Inc.	Anacortes, WA

Notwithstanding its name, this refining aggregate denotes remote refineries that (1) are capable of producing conventional gasoline, California RFG, Maricopa County gasoline, or gasoline blendstocks and (2) situated to move gasoline or blendstocks to Los Angeles.

All of the designated refineries either now supply Maricopa County or belong to companies that now supply Maricopa County from other refineries.

Aggregating the refineries of interest this way enables us to use the AGQM reports for June, July, and August 1996 to establish baseline gasolines for each aggregate. This is a considerable benefit for the analysis.

Except for Tosco, the refineries in the San Francisco refining center (e.g., Exxon, Shell, Chevron) are not now supplying Maricopa County. Moreover, their configurations (and hence their costs) are similar to those of the refineries in the Los Angeles refining center. Therefore, we concluded that leaving the other San Francisco refineries out of the West aggregate was unlikely to have a significant effect on the estimates of incremental refining costs for the proposed gasoline standards.

Exhibit 4.1 shows the crude running capacity (Bbl/day) and the processing capacity (Bbl/day), by major process unit, for each of the refineries listed above. We developed these estimates from information drawn from public sources, augmented with additional information obtained in private communications.

Exhibit 4.1: Refining Process Capacity of Gasoline Suppliers to Arizona
(barrels per calendar day)

Refiner Group/ Potential Supplying Refinery/ Location	State	Complexity	Crude Dist.	Vacuum Dist.	Thermal Operations: Delayed Coking	Thermal Operations: Fluid Coking	Cat Crack	Cat. Hydro Crack.	Cat Reforming: Low	Cat Reforming: High	Desulfurization: Gas Oil & FCC Feed	Desulfurization: Reformer Feed	Desulfurization: Naphtha & Isom F	Desulfurization: Nap. Satur.
East Refineries		[illegible]	[illegible]	[illegible]	[illegible]	0	56,100	0	38,000	9,500	0	53,500	0	0
Navajo Refining Co. - Artesia	NM	8.3	60,000	19,000			18,500		15,000			20,000		
Chevron USA, Inc. - El Paso	TX	8.1	87,000	22,000	2,400		28,000		23,000			23,000		
Shell Oil Co. - Odessa	TX	6.6	28,300				9,600			9,500		10,500		
West Refineries		[illegible]	[illegible]	[illegible]	[illegible]	42,000	404,270	208,370	84,200	192,620	419,960	241,160	5,700	28,760
Arco Products Co. - Los Angeles	CA	10.1	237,000	113,500	58,000		90,000	38,000		50,000	85,000	39,000	5,700	
Chevron USA, Inc. - El Segundo	CA	10.8	252,000	129,000	64,000		61,000	47,000		40,000	68,000	52,000		
Mobil Oil Corp. - Torrance	CA	13.8	130,000	95,000	47,500		81,900	22,700		42,000	*93,000*	22,000		
Texaco Ref. & Marketing - Bakersfield	CA	9.2	57,360	26,495	19,000			17,100	15,400			12,600		7,200
Texaco Ref. & Mkt. - Wilmington	CA	14.6	91,675	65,365	61,330		29,070	26,820		26,820	*26,460*	19,710		7,560
Tosco Corp. - Martinez (Avon)	CA	12.4	148,000	102,000		42,000	65,000	32,000	21,500	18,500	*63,000*	23,000		
Ultramar Refining - Wilmington	CA	19.2	68,000	39,000	24,000		35,000		14,000		*53,000*	22,000		14,000
Unocal Corp (76 Prod.) - Wilmington	CA	13.4	118,750	71,250	45,800		42,300	24,750	33,300	15,300	*31,500*	50,850		
Northwest Refineries		[illegible]	[illegible]	[illegible]	[illegible]	0	89,700	50,000	76,300	24,750	0	72,000	25,200	0
Arco Products Co. - Ferndale	WA	7.7	165,131	92,000	49,000			50,000	52,000			40,000		
Shell Oil Co. - Anacortes	WA	8.3	108,250	45,000			42,000		24,300			32,000		
Texaco Ref. & Mkt. - Anacortes (1/8)	WA	7.7	139,350	57,000	22,000		47,700			24,750			25,200	

Refiner Group/ Potential Supplying Refinery/ Location	State	Desulfurization: Distillate Str.R.	Desulfurization: Distillate Other	Desulfurization: Resid.	Desulfurization: FCC Gasoline	Desulfurization: Other	Other Processes: Solv. Deasph.	Other Processes: Alky-lates	Other Processes: Isomers Butane	Other Processes: Isomers Pen./Hex.	Other Processes: Cat. Polm.	Other Processes: MTBE	Other Processes: H2 (MMcfd)
East Refineries		[illegible]	[illegible]	[illegible]	[illegible]	0	0	20,800	4,500	0	0	0	0
Navajo Refining Co. - Artesia	NM	26,500						9,400					
Chevron USA, Inc. - El Paso	TX	16,500						8,200	4,500				
Shell Oil Co. - Odessa	TX							3,200					
West Refineries		[illegible]	[illegible]	[illegible]	[illegible]	0	0	93,800	8,300	19,000	2,800	6,200	572
Arco Products Co. - Los Angeles	CA	17,000	10,000					13,000			2,800	2,200	75.0
Chevron USA, Inc. - El Segundo	CA	59,000	14,000		19,000			20,000		19,000		1,700	122.0
Mobil Oil Corp. - Torrance	CA	13,000						19,000					132.0
Texaco Ref. & Marketing - Bakersfield	CA			15,300					700				24.0
Texaco Ref. & Mkt. - Wilmington	CA	13,260						7,650					68.4
Tosco Corp. - Martinez (Avon)	CA	23,000						15,000				2,300	74.0
Ultramar Refining - Wilmington	CA	6,000						9,700	7,600				
Unocal Corp (76 Prod.) - Wilmington	CA		24,000					9,450					76.3
Northwest Refineries		[illegible]	[illegible]	[illegible]	[illegible]	29,700	18,000	20,050	3,500	0	2,160	0	80
Arco Products Co. - Ferndale	WA	20,079											80.0
Shell Oil Co. - Anacortes	WA	25,000					18,000	11,500	3,500				
Texaco Ref. & Mkt. - Anacortes (1/8)	WA	14,400				29,700		8,550			2,160		

Note: Italics indicate hydrotreating processes.

Sources: Refinery Process Capacity: OGJ, December 18, 1995, p. 49-60, and 1994 Petroleum Supply Annual, EIA; Generalized Complexity Index Scores: OGJ, March 18, 1996, p. 74-80.

4.3.2 Refineries *not* represented in the analysis

Other refiners could enter the Maricopa County market in the future.

? Refineries located in the U.S. Gulf Coast region or in foreign countries from time to time ship gasoline to Los Angeles for sale in California, when market conditions in California are favorable for such imports. These refiners could supply gasoline to Maricopa County via Los Angeles harbor and the SFPP West pipeline.

  Alternatively, the Gulf Coast refiners could supply gasoline to Maricopa County via the proposed Longhorn Pipeline, should that pipeline (or a comparable one) be built.

? Giant Refining Co.'s refinery in Gallup, NM supplies portions of Arizona, and has in the past delivered gasoline to Maricopa County (by tank wagon).

? Diamond Shamrock's refinery in McKee, TX could supply gasoline to Maricopa County via a newly-opened pipeline linking it to El Paso and the SFPP East pipeline.

  The Diamond Shamrock refinery has a crude running capacity of 135 M Bbl/day and appears capable of producing at least 75 M Bbl/day of gasoline, including reformulated gasolines. Its product slate now includes federal RFG, for markets in Texas.

? MRC Refining, LLC has proposed to build a grass-roots refinery (the Maricopa refinery) south of Phoenix, which could supply Maricopa County directly, or through exchange or trade contracts.

  The Maricopa refinery would have a crude running capacity of 55 M Bbl/day. Its crude slate would comprise California crude oils (available via the All American Pipeline, whose right-of-way is adjacent to the refinery site). The refinery would produce about 27 M Bbl/day of gasoline. Its design process configuration would enable it to produce conventional or reformulated gasolines. Because it is not yet under construction, its process configuration could be tailored to produce gasoline for Maricopa County in compliance with the new gasoline standard that is adopted.

We chose not to represent any of these in the refining analysis.

We did not include the Giant Refining Co. refinery because it does not now supply gasoline to Maricopa County, and it would be a small supplier in the Maricopa County market if it were to re-enter it.

We did not include the Diamond Shamrock refinery because (1) it has not yet filed any AGQM reports, indicating that it has not yet produced any gasoline that could be sold in Maricopa County, (2) we have no information regarding the timing and extent of its prospective participation in the Maricopa County market, (3) adding it to our East refining aggregate would not produce a significant change in the estimated average incremental costs of the proposed gasloine standards, and (4) adding it to our East refining aggregate might mask the economic impacts on the West Texas/New Mexico refiners of the proposed gasoline standards.

The Maricopa refinery is not yet in existence. We did not include it because we chose not to make assumptions regarding its status or prospective start-up date.

Finally, we did not include remote refineries, such as those in the U.S. Gulf Coast refining center. U.S. Gulf Coast refiners in particular could supply Maricopa County on a sustained basis in the future, depending on the gasoline standards established for Maricopa County, circumstances in the broader gasoline market, and the existence of pipeline capacity between the Gulf Coast and El Paso (e.g., the proposed Longhorn pipeline). However, including the Gulf Coast refineries in this analysis would expand its scope unduly and would involve speculating on a number of economic and business factors outside of Arizona's control.

The entry of any or all of these refineries into the Maricopa County market would likely increase competition in the market. However, such entry(s) would be unlikely to change the overall pattern of incremental refining costs (at the refinery gate) and cost-benefit relationships among the proposed gasoline standards considered in this analysis. Establishing those incremental costs and relationships was the objective of the refining analysis.

4.4 Representing the Regional Refining Aggregates in ARMS

4.4.1 Modeling the regional refining aggregates as "notional" refineries

Within ARMS, we represented each regional refining aggregate as a "notional" refinery, denoting the region's refining capacity, process by process. For each refining aggregate, the corresponding notional refinery is a model of a single refinery that (1) runs a crude oil slate encompassing the primary crude oils actually being run in the actual refineries, (2) produces a product slate with volumes and qualities consistent with current or forecast production by the actual refineries, and (3) has process capacity and capabilities typical of the actual refineries in that aggregate.

One can think of a notional refinery as a representation of totally co-ordinated operation of the individual refineries in the specified refining aggregate. In this idealized realm, refineries trade intermediate refinery streams, blendstocks, and products so as to make optimal use of all refining capacity, process by process, regardless of the refinery(s) in which the processing capacity resides. Considerable trading of this kind actually occurs in the refining sector; but in volumes limited by physical and institutional barriers and by the capabilities of the capital stock in place.

Because a regional aggregate representation implies inter-refinery trading beyond what can actually take place, results of such analyses tend to indicate somewhat higher aggregate profit contributions and/or lower production costs than actually would occur for a given set of market conditions and regulatory requirements. The technical term for this modeling phenomenon is "over-optimization". Over-optimization is characteristic of all model-based analysis of the refining sector that involves modeling aggregate refining capacity. However, with good modeling practice, one can limit the effects of over-optimization and produce robust results useful for planning and policy recommendations.

4.4.2. Summary description of the notional refineries

Exhibits 4.2, 4.3, and 4.4 summarize in tabular form the configuration of the three notional refineries. These configurations constitute the point of departure for analyzing the reference case and the various fuel formulation cases (as discussed in Section 4.5).

Exhibit 4.2: Refining Process Capacity for Refinery Aggregates and Notional Refineries
(barrels per calendar day)

Refining Processes	Refinery Aggregates: East	Refinery Aggregates: West	Refinery Aggregates: North-west	Notional Refineries: East	Notional Refineries: West	Notional Refineries: North-west
Number of Refineries	3	7	3	-	-	-
Complexity	8.0	12.1	7.9	8.0	12.1	7.9
Distillation:						
Crude Distillation	175,300	1,109,285	427,150	60,000	150,000	150,000
Vacuum Distillation	51,000	645,610	194,000	-	-	-
Conversion Processes:						
Fluid Cat Cracking	56,100	404,270	89,700	19,200	54,700	31,500
Hydrocracking	0	208,370	50,000	0	28,200	17,600
Coking: Delayed	2,400	319,130	71,050	800	48,800	25,000
Coking: Fluid	0	42,000	0	0	0	0
Upgrading Processes:						
Alkylation	20,800	93,800	20,050	7,100	12,700	7,000
Cat Polymerization	0	2,800	2,160	0	400	800
Pen/Hex Isomerization	0	19,000	0	0	2,600	0
Reforming: Low Pressure	38,000	84,200	76,300	13,000	11,400	26,800
High Pressure	9,500	192,620	24,750	3,300	26,000	8,700
Oxygenate Production:						
MTBE Plant	0	6,200	0	0	800	0
Desulfurization:						
Distillate	42,800	196,880	59,400	14,600	26,600	20,900
FCC Feed	0	419,960	0	0	56,800	0
Naphtha & Isom Feed	0	5,700	25,200	0	800	8,800
Reformer Feed	53,500	241,160	72,000	18,300	32,600	25,300
Resid	0	15,300	0	0	2,100	0
Other Processes:						
Solvent Deasphalting	0	0	18,000	0	0	6,300
Isomerization: C4	4,500	8,300	3,500	1,500	1,100	1,200
Hydrogen Plant (MM cf/d)*	0	572	80	0	77	28

* Conversion to FOEB -- 21,000 SCF/FOEB.

Source: Derived from Exhibit 4.1.

Exhibit 4.3: Crude Oil and Other Inputs for the Notional Refineries*
(thousands barrels per day)

Inputs/ Outputs	API Gravity	Specific Gravity	% Sulfur	Notional Refineries East	West	Northwest
Crude Oil Inputs:						
Composite: Light, LoSulfur	36.3	0.843	0.38%	45		
Composite: Medium, MedSulfur	33.2	0.859	1.47%	13		
Composite: West Domestic	20.0	0.934	1.24%		66	
Composite: West Imports	29.7	0.8776	1.23%		13	
Alaskan North Slope	27.5	0.89	1.11%		71	119
Canadian Peace River	39.2	0.829	0.45%			31
Total:				**58**	**150**	**150**
Average Crude Oil Quality:						
API Gravity				35.6	24.3	29.7
Specific Gravity				0.847	0.908	0.878
Sulfur Content (%)				0.63%	1.18%	0.98%
Other Inputs:						
Alkylate					2	
Isobutane				1.4	1	
Gas Oils					3	
MTBE					6.3	
Methanol					0.3	
Naphtha					1	
Natural Gas Liquids					1.3	

* Summer 1996 baseline/

Exhibit 4.4: Product Outputs for the Notional Refineries*
(thousand barrels per day)

Inputs/ Outputs	Notional Refineries East	West	Northwest
LPGs	1.6	5.0	5.3
Alkylate	-	-	3.0
Gasoline	[illegible]	[illegible]	[illegible]
Conventional	20.0	9.0	53.0
Maricopa Co.	8.0	9.0	7.0
California RFG	-	72.0	4.0
Jet Kerosene	4.0	22.0	15.0
Distillate	17.0	[illegible]	[illegible]
Low Sulfur	12.0	23.0	22.0
High Sulfur	5.0	8.0	25.0
Gas Oil	-	-	7.0
Residual Oil	4.0	1.0	[illegible]
< 0.7% Sulfur	1.0	-	-
> 3.0 % Sulfur	3.0	1.0	7.0
Asphalt	3.0	2.0	-
Coke	0.2	9.7	4.4
Total	57.8	[illegible]	[illegible]

* Summer 1996 baseline.

Exhibit 4.2 shows

? The *aggregate* process capacity (in Bbl/day) of the refineries in each of the three refining aggregates specified in Section 4.3; and

? The process capacity profiles for each *notional* refinery; that is, the individual process units and the through-put capacity (in Bbl/day) of each unit in each notional refinery.
Entered into the ARMS database, these values established the physical configuration of the notional refineries in the reference cases (that is, before addition of any new processing capacity called for to produce the various fuel formulation options).

Exhibits 4.3 and 4.4, respectively, show our estimates of the primary inputs and outputs of each notional refinery; that is, the crude slates run and the refined product slates produced by each notional refinery.

Recall that Exhibit 2.1 shows the weighted average CM properties of the Maricopa County gasoline pool for June, July, and August 1996, drawn from the monthly AGQM reports submitted to Arizona by refiners producing gasoline to Maricopa County specifications.

From these reports, we estimated average CM properties not only for the entire Maricopa County Summer 1996 gasoline pool, but also for the shares produced by the East, West, and Northwest refineries. For reasons of confidentiality, we do not show average CM properties by region. But the average CM properties specific to each refining center are represented in the reference cases for the notional refineries, and they define the baseline Maricopa County gasoline for the corresponding notional refineries.

As Exhibit 4.4 indicates, we asked the notional refineries to produce fixed volumes of gasoline in connection with each of the fuel formulation options -- including those involving oxygenate blending. That is, we did *not* ask the notional refineries to produce additional volumes of gasoline to match the volumes of oxygenate purchases in those regulatory cases that involve oxygenate blending (e.g., federal RFG).

4.5 Primary Steps in the Analysis

Consistent with our usual practice, the refining analysis for this project comprised three steps, carried out for *each* notional refinery.

4.5.1 Develop technical description of the refineries of interest

This step involved establishing the process capacities, process capabilities, crude oil slate, product slate, gasoline grade splits, product specifications and qualities as produced, for the time period(s) of interest.

We obtained information on the refineries of interest from various publications, private communications, discussions with staff members at some of the refineries of interest, and inference. We organized and analyzed this information using MathPro Inc.'s proprietary "netback" model of refining operations. This spreadsheet model is an approximation of the ARMS model. We used it to develop internally consistent initial estimates of crude slates, product out-turns, and gasoline properties that serve as inputs to ARMS.

4.5.2 Establish the calibration and reference case

Calibration involved setting up and solving a base case in ARMS to verify that the refinery LP model in ARMS and the technology data (e.g., process yields, blendstock properties) in ARMS were consistent with the current operations of the refinery(s) of interest. Where we found inconsistencies, we adjusted the technology data as needed. Calibration is a crucial element of any refinery analysis.

In this analysis, calibrating the West notional refinery posed a particular challenge in one respect. We found it necessary to adjust a number of blendstock properties -- in particular, the distillation curves for all FCC gasoline and reformate blendstocks -- in order to match the reported distillation curve for the West baseline gasoline. (We discussed this particular issue in detail with interested members of the Subcommittee.)

Establishing the baseline conditions and values involved setting up and solving a reference case in ARMS. The solution to the reference case characterized the technical and economic performance of the notional refineries at present or in a specified future year, *before* imposition of prospective new regulations or standards (such as the fuel formulation options).

Usually, calibration and reference cases are separate: the former applies to the current year or a prior one; the latter applies to a future year of interest (e.g., 2000). However, for various reasons, we combined the calibration and reference steps in this analysis. The calibration and reference case represented the 1996 Summer season.

> Some members of the Subcomittee have suggested that the reference case apply to the *1998* Summer season, because the federal anti-dumping requirements for conventional gasoline become more stringent in 1998. In principle, this suggestion is reasonable. However, the AGQM for June, July, and August 1996 indicate that (1) most of the refiners are already in compliance with the 1998 requirements and (2) those who aren't in compliance are close to it. We concluded that the 1996 Summer season was a suitable basis for the reference case.

4.5.3 Evaluate each proposed gasoline standard

This step produced the results of interest. It involved using ARMS, for each fuel formulation option, to simulate refinery operations and estimate refining costs for producing a product slate that included gasoline for Maricopa County (conforming to the given fuel formulation option).
The results of each simulation (or regulatory case, in our parlance) included the volume and quality of each product in the product slate; the composition of each gasoline grade slate (including that produced for Maricopa County), the marginal cost of each gasoline produced, total direct operating costs (excluding fixed and sunk costs), and the capital investment requirements for new or upgraded refining capacity.

Detailed item-by-item comparison of these results with the corresponding results of the reference case produces the incremental refining cost (in cents per gallon of Maricopa County gasoline) and the additional capital investment requirements associated with each fuel formulation option. In turn, analysis of these results illuminated other potential impacts of the various fuel formulation options (such as possible changes in the relative economics of the East and West refining centers now serving Maricopa County).

4.6 Key Analytical Issues, Assumptions, and Input Data Elements

4.6.1 Focus on "quality hold" operations

In producing federal RFG (Options 1 and 2) for Maricopa County, refiners would have to comply with federal anti-dumping standards for their conventional gasoline out-turn. In particular, refiners could not improve the "environmental quality" of Maricopa County gasoline by modifying (degrading) the environmental quality of that portion of their gasoline production subject to the anti-dumping standards.

In producing the other fuel formulation options for Maricopa County, refiners would have to comply with federal anti-dumping standards on their entire conventional gasoline out-turn -- including Maricopa County gasoline. Within their conventional gasoline pools, refiners could -- in principle -- trade off environmental quality between Maricopa County gasoline and other gasolines. That is, producing Maricopa County gasoline could be accomplished, in whole or in part, through suitable changes in blending recipes and operations. We refer to this approach as "quality shifting".

Arizona would not be in a position to know the environmental quality of gasolines produced for delivery to markets other than Maricopa County nor to establish standards for gasolines produced for delivery outside of Arizona.

Consequently, we initially modeled operations of the notional refineries producing each fuel formulation option (except for the federal RFG options) in each of two ways.

- ? One way, which we called "quality hold", represented refining operations that would produce the given fuel formulation option for Maricopa County with no accompanying reduction in the environmental performance of gasolines produced for sale outside of Maricopa County.

- ? The other way, which we called "quality shift", represented refining operations that would produce the given fuel formulation option for Maricopa County so as to comply with the federal anti-dumping standard on the entire gasoline out-turn.

  Gasoline produced for sale outside of Maricopa County could be subject to some reduction in environmental performance, within the limits imposed by the federal anti-dumping standard.

  Quality shifting would require that the refiner have the requisite tankage, blending, and oil movements facilities to produce and segregate the various gasoline grades involved. In considering these cases, we assumed that the facilities would be available.

Our initial analysis showed that, for any given fuel formulation option where the choice existed, "quality hold" would lead to higher incremental refining costs than "quality shift".

We initially considered these two sets of cases for three reasons.

- ? The SoW calls for consideration of potential impacts of the fuel formulation options on areas outside of Maricopa County.

- ? Comparison of "quality hold" and "quality shift" operations illuminated interactions and trade-offs among (1) incremental refining costs, (2) the environmental performance of Maricopa County gasolines, and (3) the environmental performance of other gasolines (destined for other markets) co-produced with Maricopa County gasolines.

- ? Arbitrarily choosing only one of the two sets of cases for analysis, would -- in effect -- have put us in the position of anticipating decisions that various entities would make on an issue of strategic, economic, and environmental importance. That was neither our charter nor our intent.

Members of the Subcommittee, most notably those from the refining sector, made a strong representation that only "quality hold" operations would be appropriate and acceptable. No members of the Subcommittee challenged this representation.

Consequently, we focused our final round of analysis and all of our reporting efforts on "quality hold" operations. The results and findings reported in Section 6 all apply to "quality hold" operations -- refining operations that would produce the given fuel formulation option for Maricopa County with no accompanying reduction in the environmental performance of gasolines produced for sale outside of Maricopa County. .

4.6.2 Specifying the volume of gasoline to be produced with oxygenate blending

As noted in Section 4.4.2, we did *not* ask the notional refineries to produce additional volumes of gasoline to match the volumes of oxygenate purchases in those regulatory cases that involve oxygenate blending (e.g., federal RFG). Had we done so, those cases would have shown lower incremental costs -- but only slightly lower.

In prior studies, we have analyzed the economics of gasoline production with oxygenates with and without incremental volumes of gasoline production to match the volumes of oxygenate blended. We have found that estimates of the economics of gasoline production (measured by both incremental and marginal costs) are relatively insensitive to one's assumptions regarding gasoline volume.

Our prior work suggested that had we asked the notional refineries to produce additional volumes of gasoline to match the volumes of oxygenate purchases, the resulting incremental refining costs for the given fuel formulation options would have been roughly 0.1-0.2 ¢/gal lower than the costs we estimated.

We explored the incremental volume issue further in this analysis. In particular, we ran two sensitivity cases for the West notional refinery, in which we set Maricopa County gasoline volumes such that crude throughput remained the same as in the reference case. In other words, we increased total gasoline out-turn in step with the volume of oxygenate purchases.

For the federal Phase 2 RFG option, this change reduced the option's incremental refining cost by about **?** ¢/gal (relative to our original estimate). For the California RFG option, it reduced the option's incremental refining cost by just over ½ ¢/gal (relative to our original estimate).

4.6.3 Changes in fuel economy resulting from changes in energy density

A gasoline's fuel economy is proportional to its energy density (expressed in MM BTU/Bbl or in M BTU/gal). Physical considerations dictate that energy density decreases with increasing oxygen content, increasing distillation values (i.e., E200 and E300), and increasing RVP. The ARMS model captures all of these effects.

For each gasoline grade represented, ARMS computes the energy density (in MM BTU/Bbl) along with the CM properties and other properties of interest. This enables us to include the cost of the estimated gain or loss in fuel economy (miles/gal) in the total incremental cost of a proposed gasoline standard.

We used the following formula to estimate the cost *to Maricopa County* of a change in fuel economy associated with a proposed gasoline standard.

D Fuel economy cost (¢/gal) = D ED (%) * [ARP (¢/gal) + IRC (¢/gal)]

where

D ED is the change in energy density with respect to the baseline gasoline, expressed as a percentage of the energy density of the baseline gasoline;
ARP is the average retail price of gasoline in Maricopa County (including federal but *not* state tax) -- close to 125 ¢/gal. in the Summer 1996 season ; and

IRC is the incremental refining cost of proposed gasoline standard.

This formula is consistent with EPA's approach in assessing the costs of the federal RFG program.

4.6.4 Key assumptions and input data

This section highlights some of the key assumptions and input data elements that went into the calibration and reference case and the regulatory cases for each notional refinery.

These highlights are likely to be of interest mainly to those Subcommittee members who are conversant with refining analysis.

? Crude oil slates

Drawn from information in public sources (trade publications and U.S. Department of Energy surveys) and consistent with (1) reported sulfur contents of gasoline batches prepared to Maricopa County standards and (2) capacity profiles of the notional refineries

? Prices of input streams ($1996/Bbl)

Crude oil	$20	
i-butane	$18	
n-butane	$17	
MTBE (West)	$39.90	($0.95/gal)
(East)	$37.80	($0.90/gal)

? Reference case period

Summer 1996. No 1998 reference case appeared warranted, because (1) most supplies to Maricopa County are already in compliance with EPA's 1998 anti-dumping standard and (2) the Maricopa County pool as a whole is already in compliance.

? Gasoline grade slates represented in the reference cases

-- East: Conventional gasoline with quality similar to current average East quality, from the AGQM reports for Summer 1996 (Exhibit 2.2)

-- West: CARB RFG, with composition computed endogenously, and conventional gasoline with quality similar to current average West quality, from the AGQM reports for Summer 1996 (Exhibit 2.2)

-- Northwest: Conventional gasolines, with qualities similar to current average Northwest quality as estimated from gasoline quality surveys published by the National Institute for Petroleum and Energy Research (NIPER) for 1995 and prior years

? Gasoline grade slates represented in the reference cases

	CARB RFG	Conventional	Maricopa County
-- East		X	X
-- West	X	X	X
-- Northwest		X	X

(The designation "Maricopa County" means gasoline grade slates corresponding to the various fuel formulation options.)

? Investments in new process capacity

-- Recover capital costs in the Summer season only (i.e., use standard capital recovery factors multiplied by 2).

-- Allow no investment in new captive oxygenate units (i.e., all additional MTBE obtained from merchant sources).

-- Increase capital costs and capital recovery factors as appropriate for investments in new process units of smaller-than-standard capacities.

-- Adjust capital costs for location by multiplying the standard capital cost values in ARMS (which are applicable to the U.S. Gulf Cost) by the following coefficients.
  - East 1.10
  - West 1.40
  - Northwest 1.18

? Segregation of Maricopa County gasoline

On the basis of our analysis of quality give-away, discussed in Section 3.5.3, we assumed -- for all fuel formulation options -- that Maricopa County gasoline would be fully segregated from other gasolines produced by refineries supplying Maricopa County.

5. ANALYSIS OF EMISSIONS REDUCTIONS ASSOCIATED WITH THE FUEL FORMULATION OPTIONS

In the SoW, the statement of **Task 4** (Emissions Analysis) calls for ". . . assess[ing] the emissions impact of each option identified in Task 1, using established, peer-reviewed models and analytical methods. . .".

This section addresses the emissions analysis; that is, the methodology used in this project for estimating the emissions impacts of the fuel formulation options. The section covers five topics:

1. Emissions of interest
2. Sources of these emissions
3. Established emissions models
4. The emissions models of choice for this analysis
5. Baseline emissions

5.1 Emissions of Interest

The vehicle emissions of interest for this analysis are

? Volatile organic compounds (**VOC**)
-- Exhaust
-- Non-exhaust (evaporative, running loss, re-fueling)

? Nitrogen oxides (**NOx**)

? Toxics (in particular, the organic compounds benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and polycyclic organic material (POM))

? Carbon monoxide (**CO**)

? Particulate matter (**PM**)

Gasoline properties can influence the levels of all of these emissions.

VOC and NOx emissions are the most important ozone precursors. Of these, VOC is the primary focus of this analysis. NOx received secondary consideration, for reasons discussed below. The other emissions also received secondary consideration -- pursuant to the SoW.

5.1.1 VOC emissions

All else equal, ozone concentration in the atmosphere always increases with increasing VOC concentration. VOC's effect on ozone level varies depending on the mix of VOCs in the atmosphere, the relative level of ambient NOx, meteorological factors (such as temperature and wind speed), and other factors.

Certain VOC species, such as olefins (i.e., hydrocarbons containing one or more double bonds between carbon atoms), are especially reactive with respect to ozone formation under most conditions. Straight chain paraffins (hydrocarbons containing neither double bonds or aromatic rings) tend to be less reactive. Thus, focusing only on reducing mass emissions of VOC can be misleading if most of the VOCs being reduced are among the most or least reactive. Changes in mass VOC emissions can be particularly misleading if the least reactive VOCs are reduced while emissions of more reactive VOCs are increased, or vice versa.

Some of the fuel formulation options could lead to shifts in relative reactivity of VOC emissions. Consequently, we attempted to consider the relative reactivity of the VOC emissions in assessing the VOC reductions yielded by the various fuel formulation options.

5.1.2 NOx emissions

NOx's role in ozone formation is ambiguous and more complex than VOC's. Under some conditions, ozone concentration increases with increasing NOx emissions (as with VOC). Under other conditions, the relationship is inverse: ozone concentration increases with *decreasing* NOx emissions.

Previous UAM modeling of the Maricopa County airshed indicated that decreasing NOx emissions would increase ambient ozone levels. ADEQ is now conducting an updated and more detailed UAM effort. Results of this effort could confirm the previous finding, or show that reducing NOx emissions would decrease ambient ozone levels.

Because the role of NOx emissions in the Maricopa County airshed is uncertain, the SoW specified fuel formulations options aimed at reducing VOC emissions. Nonetheless, we estimated the effects of the fuel formulation options on NOx emissions. Hence, the findings of the analysis should be useful whether or not the current air quality modeling effort leads to the finding that NOx control is indeed important for reducing ozone concentration in the Maricopa County airshed.

5.1.3 Other emissions

Gasoline properties affect other emissions from vehicles, such as CO, toxics, and particulate matter (PM). Though of secondary importance in this analysis, these pollutants are important from the public health standpoint. Hence, we estimated the effects of the fuel formation options on these emissions as well, albeit in a more approximate manner than VOC and NOx emissions.

5.2 Sources of Emissions

Two classes of emissions sources use gasoline: on-road vehicles (passenger cars, light and heavy trucks, and motorcycles) and off-road equipment (lawnmowers, garden tractors, leaf blowers, generators, etc.).

Our emissions analysis focused on on-road vehicles because (1) they are the more important contributor to the VOC emissions inventory and (2) the effects of gasoline properties on emissions is best understood for on-road vehicles. We considered off-road equipment to the extent possible (with the available analytical tools), because their emissions form a significant part of the VOC emissions inventory.

5.2.1 Vintages of on-road vehicles

Emissions from on-road vehicles have been regulated for more than twenty years and studied even longer. Current vehicle emission standards reduce VOC, NOx, and CO emissions (in g/mile) by 90%-95% relative to former, uncontrolled levels.

Because of the progressively more stringent regulation of on-road vehicles, the technology applied to emission control has changed over time. The different vintages of emission control technology respond differently to changes in gasoline properties. Therefore, it is customary to consider different technology vintages -- and hence, vehicle vintages -- in analyzing the effects of gasoline properties on vehicle emissions technology.

For example, high sulfur content in gasoline reduces the efficiency of catalytic converters that treat engine exhaust. However, if a vehicle does not have a catalytic converter, then gasoline sulfur level has no impact on its emissions.

In this analysis, we considered three groupings of vehicles:

? Pre-1981 model years

? 1981-1985 model years

? 1986 and later model years

5.2.2 Off-road equipment

Emission standards for gasoline-fueled non-road engines were first implemented for new engine sold in 1996.

As with on-road vehicles, different non-road engines may respond differently to changes in gasoline properties. Only limited information is available from which to project the effects of gasoline properties on the emissions produced by off-road equipment.

The problem is especially acute for two-stroke engines. Emissions data for four-stroke engines (used in cars and trucks) cannot be applied to two-stroke engines, because two-stroke and four-stroke engines are of fundamentally different design. Hence, we did not address non-road emissions from two-stroke engines in this analysis.

Four-stroke non-road engines are of simple design, relative to current on-road engines. They are subject to a lower level of emission control than on-road engines. They are similar, in emissions performance, to on-road vehicles of pre-1975 vintage. Unfortunately, little is known regarding the effects of gasoline properties on emissions from these vehicles. Hence, we estimated the emissions from four-stroke off-road engines by extrapolating information on emissions of later-vintage on-road vehicles.

5.3 Emissions Models

Two types of established, peer-reviewed models exist for estimating the effects of gasoline properties on vehicle emissions:

? Vehicle fleet emission models

-- **MOBILE5a** developed by the U.S. Environmental Protection Agency (EPA)
-- **EMFAC7g** developed by the California Air Resources Board (CARB)
-- **PART5** a simplified version of MOBILE5a, focusing on PM emissions only

? Gasoline certification models

- -- The **Complex Model** developed by EPA for the federal Phase 1 and Phase 2 RFG programs
- -- The **Predictive Model** developed by CARB for the California Phase 2 RFG program

Estimating the effects of a proposed fuel formulation option on total in-use vehicle emissions calls for coordinated use of a model of each type.

We evaluated each of these models in the course of this project

5.3.1 Vehicle fleet emission models

These models are designed to estimate daily (Summer and Winter season) in-use emissions of VOC, NOx, and CO of the entire on-road vehicle fleet in a specific area (in a specific year), given (1) the make-up of the vehicle fleet (by type and vintage), (2) local conditions (climate, driving patterns, etc.), and (3) existing and proposed regulatory programs (e.g., advanced I/M programs).

Vehicle fleet emission models are intended for evaluating regulatory programs and strategies and (in the case of MOBILE5a) for preparing State Implementation Plans (SIPs) for achieving the National Ambient Air Quality Standards.

MOBILE5a recognizes vehicles manufactured for sale outside California; it also recognizes the 1990 national baseline gasoline (with and without RVP control and oxygenate addition) and federal RFG, but no other fuel formulations. EMFAC7g recognizes only California gasolines (pre-RFG, Phase 1 RFG and Phase 2 RFG) and California emission standards for new vehicles. Hence, MOBILE5a is more applicable for estimating vehicle emissions in Maricopa County.

MOBILE5a reflects the impacts of new vehicle standards, local emission control programs, and in-use deterioration of vehicles' emission control equipment.

PART5 provides projections similar to those provide by MOBILE5a, but for emissions of inhalable PM (PM10). PART5 is the only model available that addresses vehicle emissions of PM10.

5.3.2 Gasoline certification models

These models are designed for certifying, at the refinery and points in the distribution system, that given volumes of gasoline are in compliance with the performance-based emissions standards (per-gallon or average) of the RFG program to which they apply.

In particular, they estimate the VOC, NOx, and toxics emissions performance of a given gasoline (for a given mix of vehicle types) as a function of specified properties of that gasoline (those we call the CM properties). The Complex Model also addresses CO emissions.

The gasoline certification models consider only a limited range of vehicle types and in-use conditions (in comparison with the vehicle fleet emission models).

> The Complex Model represents vehicle technology typical of 1990 vintage vehicles, because of a requirement of the Clean Air Act Amendments that the mandated performance of federal RFG be determined using such vehicles. In general, this representation covers 1986-1994 vintage vehicles. (Most vehicle manufacturers assert that the Complex Model's representation is less valid for vehicles of 1993 and later vintage than for older vehicles.)
>
> The Predictive Model recognizes two vehicle technology groups. Technology Group 4 (Tech 4) applies to 1986 and later vintage vehicles. Technology Group 3 (Tech 3) applies to 1981- 1985 model year vehicles. (This vehicle technology incorporated closed-loop, feedback control but not port fuel injection or adaptive learning.) CARB attempted to represent technology groups for older vehicles (Tech 1 and Tech 2), but were forced to abandon the effort for lack of data.

Because they embody empirical relationships between CM properties, over a range for each, and emissions performance, the gasoline certification models are especially useful for estimating the effects on emissions performance of prospective changes in gasoline properties. In this regard, the Complex Model offers more generality than the Predictive Model, because the latter is tailored to the standards of the California RFG program.

Appendix C provides a detailed comparison and assessment of the Complex Model and the Predictive Model.

5.4 Emission Models of Choice for This Analysis

Exhibit 5.1 shows the set of models that we selected for this analysis to estimate the effects of the fuel formulation options on the various vehicle emissions of interest.

Our reasons for these selections are summarized briefly below (and discussed more fully in **Appendix D**).

5.4.1 Exhaust VOC, NOx, and toxics

As Exhibit 5.1 indicates, we considered three vintages of on-road vehicles: 1986 and later, 1981-1985, and pre-1981.

We chose to use both the Complex Model and the Tech 4 portion of the Predictive Models for the 1986 and later vintage vehicles. Both apply to the 1986 and later vintage, and both were developed from essentially the same set of emissions data.

We also chose to use both the Tech 3 portion of the Predictive Model and the Complex Model for the 1981-1985 vintage vehicles. The data from which the Complex Model was developed explicitly excludes this vehicle vintage, and its technology is unlike that of the newer vehicles that are represented in the Complex Model. However, the Complex Model was applied nonetheless to estimate the sensitivity of the results to use of the Complex Model instead of the Predictive Model throughout the range of vehicle vintages.

Exhibit 5.1: Emission Models of Choice

Pollutant	Vehicle Model Year Group	Emissions Model
Exhaust VOC, NOx, and toxics	1986 and later	Complex Model Predictive Model (Tech4)
	1981-85	Complex Model Predictive Model (Tech3)
	Pre-1981	Complex Model (without impact of sulfur on NOx) Predictive Model (Tech3, without impact of sulfur on NOx)
	Non-Road	Complex Model (without impact of sulfur) Predictive Model (Tech3, without impact of sulfur)
Exhaust CO	All	Complex Model
Non-Exhaust VOC	All	MOBILE5a
Non-Exhaust Benzene	All	MOBILE5a with Complex Model
Ozone	All	Auto-Oil
Particulate (PM)	All	PART5 plus Bowman, Pilinis and Seinfeld[1]

We also selected both the Complex Model and the Tech 3 portion of the Predictive Model for the pre-1981 vintage. Neither model explicitly represents vehicles of this vintage, though the 1981-1985 vintage vehicles contained in the Tech 3 model more closely approximate pre-1981 technology. However, significant differences do exist, and directly applying the 1981-1985 representation to the older vintage is not desirable. So, we removed the emission impact of

[1] Bowman, Frank M., Pilinis, Christodoulos, and Seinfeld, John H.; *Ozone and Aerosol Productivity of Reactive Organics*; Atmospheric Environment; Volume 29, No. 5

gasoline properties that would have no effect on the emissions performance of pre-1981 vehicles (i.e., the effect of fuel sulfur on NOx emissions).

5.4.2 Non-exhaust VOC

We chose MOBILE5a here because (1) it contains all of the gasoline property effects registered in the Complex Model and (2) it can be applied to the largest variety of end-use situations.

5.4.3 Exhaust CO

EPA has recently published a CO emission model developed from the same database as the Complex Model using the same statistical techniques. For the purpose of this study, we consider this CO emission model part of the Complex Model.

The Complex Model is the only model available that deals with CO emissions.

5.4.4 Non-exhaust benzene

The Complex Model and MOBILE5a are the only models available that deal with non-exhaust benzene emissions.

5.4.5 PM10

PART5 is the only model available that deals with PM10 emissions. As indicated, we augmented PART5 with results of recent research.

5.5 Baseline Emissions

This section delineates our estimates of the baseline emissions for this analysis. As noted in Section 2, the baseline period for the analysis is Summer 1996.

5.5.1 Baseline emissions of VOC, CO and NOx from on-road vehicles

As noted in Section 1, Arizona is now conducting urban airshed modeling in conjunction with its State Implementation Plan for ozone. This UAM modeling focuses on an ozone episode that occurred on August 9 and 10, 1992. For consistency between this study and the UAM work, we used baseline emission inventories from the UAM modeling to the fullest extent possible.

In particular, we obtained from ADEQ estimates of (1) daily emissions of VOC, CO and NOx emissions in Maricopa County consistent with the August 10, 1992 ozone episode for future calendar years 1996, 1999, and 2010[2] and (2) vehicle-miles-traveled (VMT) for this day. We estimated daily average emission factors for each pollutant by dividing the emission inventories by the vehicle miles travelled. **Exhibit 5.2** shows these emission inventories and the calculated emission factors.

Exhibit 5.2: UAM Baseline Phoenix VOC, CO and NOx Emissions

	VOC	CO	NOx
Emission Inventories (metric tons/day): August 10, 1992 Meteorology			
1996	101.65	749.6	144.21
1999	96.39	715.95	141.10
2010	75.29	544.81	139.34
Emission Factors (g/mi)			
1996	1.85	13.65	2.63
1999	1.61	11.96	2.36
2010	0.97	7.04	1.80

These emissions and emission factors cover emissions from both diesel and gasoline-fueled vehicles. As only gasoline reformulation is being considered in this study, separate emission factors for gasoline-fueled vehicles are desired. We used MOBILE5a to separate diesel from gasoline vehicle emissions, using inputs obtained from ADEQ that are consistent with the above emission inventories.[3] We applied the breakdowns of emissions between gasoline-fueled and diesel vehicles and those between exhaust and non-exhaust VOC emissions from these MOBILE5a runs to the emission factors listed in Exhibit 5.2 to estimate emissions from gasoline-fueled vehicles under the conditions of the UAM modeling runs.

2 August 10 was chosen over August 9, as the highest ozone concentrations occurred on the 10th. August 10 was also a Monday, with higher levels of vehicle miles travelled than the 9th, a Sunday.

3 The only difference was our use of a single average vehicle speed of 30 mph, which is near the average in-use speed of 32 mph. The relationship between speed and emissions is not linear. Usually, MOBILE5a is run for a wide range of vehicle speeds and the resultant emission factors weighted together using the in-use frequency of vehicle speeds. However, this process is very resource intensive. The use of a single, average speed should be sufficiently accurate for the purpose of splitting diesel and gasoline vehicle emissions.

MOBILE5a has limited flexibility in modeling the emission impacts of gasoline quality. The user can specify oxygenated gasoline or Federal RFG and can specify the gasoline RVP. If oxygenated gasoline or Federal RFG are not selected, MOBILE5a assumes that gasoline has the composition of national average gasoline sold in 1990 at the selected RVP level. Current gasoline quality in Maricopa County differs substantially from that of 1990 national average gasoline. Accordingly, we estimated the effects of the difference in composition between current Maricopa County fuel and 1990 national average fuel on exhaust VOC, CO and NOx emissions, using both the Complex and Predictive Models.

We also adjusted non-exhaust VOC emissions to reflect the current Maricopa County standard. The UAM modeling assumes 7.0 RVP gasoline. As indicated in Sections 1 and 2, Mariopa County's current RVP standard is 7.0, but in-use fuel generally has lower RVP to ensure compliance. Current Maricopa County fuel averages 6.7 RVP, so we adjusted non-exhaust VOC emissions to reflect this RVP level.

Exhibit 5.3 shows the effect of fuel quality on exhaust emissions. **Exhibit 5.4** shows the final baseline emission factors and emission inventories for gasoline-fueled vehicles in 1999 and 2010.

Exhibit 5.3: Maricopa County Gasoline Vs. CAA Baseline Gasoline
(% Change in Emissions *)

	Exhaust VOC	CO	NOx
1999 Calendar Year Average Effect			
Complex Model	2.0%	-3.2%	-5.4%
Predictive Model	2.4%	---	-5.8%
2010 Calendar Year Average Effect			
Complex Model	2.0%	-3.2%	-5.8%
Predictive Model	1.7%	---	-7.2%

* Negative numbers indicate decreased emissions relative to CAA Baseline fuel.

Exhibit 5.4: Baseline Phoenix Emission Factors for Current Fuel Quality (g/mi)

	Exhaust VOC	Non-Exhaust VOC	CO	NOx
1999 Calendar Year				
Complex Model	0.869	0.628	11.044	1.557
Predictive Model	0.873	0.628	11.044	1.549
2010 Calendar Year				
Complex Model	0.583	0.340	6.344	1.201
Predictive Model	0.581	0.340	6.344	1.183

As discussed above, we used both the Predictive and Complex models to project the emission effects for the various vehicle vintages. We estimated the percentage of fleet-wide light-duty vehicle and light-duty truck emissions attributable to each model year grouping using MOBILE5a, with vehicle registration distributions and an inspection and maintenance (I/M) program consistent with that assumed in the urban airshed modelling. These percentages are shown in Exhibit 5.5 for calendar year 1999. In 2010, per MOBILE5a, all vehicles are 1986 and later model year vehicles (MOBILE5a only tracks vehicles until they are 24 years old.)

Exhibit 5.5: Breakdown of Emissions by Vehicle Grouping for Calendar Year 1999

	Complex Model		**Predictive Model**	
	Exhaust HC	NOx	Exhaust HC	NOx
1986+	69.2%	78.2%	69.2%	78.2%
1981-1985	12.9%*	11.6%*	17.0%	15.3%
1975-1980	17.9%**	10.2%**	13.8%	6.5%
Total	100.0%	100.0%	100.0%	100.0%

* Excludes 1981-1985 vehicles with oxidation catalysts
** Includes 1981-1985 vehicles with oxidation catalysts

The Predictive Model contains sub-models that apply to 1981-1985 and 1986 and later vehicles, so the first two model year groupings shown in Exhibit 5.5 are easily modeled. As discussed in

Appendix D, we represent pre-1981 vehicles as 1981-1985 vehicles, except that the gasoline sulfur content is assumed to have no impact on NOx emissions.[4]

As noted earlier, the Complex Model applies only to vehicles with 1990 model year technology. Thus, it is more difficult to model emissions of earlier vintage vehicles. To approximate the difference between 1990 and older technology, we assumed that changes in fuel sulfur do not affect NOx emissions from pre-1981 vehicles, as well as post-1980 vehicles equipped only with oxidation catalysts.

We computed baseline emission inventories from the factors shown in Exhibit 5.4, using ADEQ's estimate of total VMT in Maricopa County in 1999 and 2010 -- 59.9 and 77.4 million miles per day, respectively. **Exhibit 5.6** shows the baseline VOC, CO and NOx emissions, in tons/day.

Exhibit 5.6: Baseline VOC, NOx, and Toxic Emissions in Maricopa County (metric tons/Summer day)

	Exhaust VOC	Non-Exhaust VOC	CO	NOx
On-road Vehicle Emissions				
Calendar Year 1999				
Complex Model	52.0	37.6	661.1	93.3
Predictive Model	52.1	37.6	661.1	92.9
Calendar Year 2010				
Complex Model	45.1	26.3	490.7	92.9
Predictive Model	44.8	26.3	490.7	91.5

[4] Nearly all vehicles produced prior to the 1981 model year used oxidation catalysts, which reduce only VOC and CO emissions. Fuel sulfur affects emissions by reducing catalyst efficiency. As NOx emissions from these vehicles were never affected by a catalyst, fuel sulfur should have no impact on these emissions.

5.5.2 Baseline emissions of VOC, CO and NOx from non-road engines

Emissions from non-road equipment represent a significant fraction of the VOC and CO emissions inventories in Maricopa County. NOx emissions from non-road engines are low relative to the other two pollutants and generally comprise a negligible portion of the total NOx emission inventory in a given area.

Exhibit 5.7 shows baseline VOC, CO and NOx emission inventories for non-road engines provided by ADEQ for calendar year 1993. ADEQ also provided projections of growth in equipment usage between 1993 and 1996, 1999 and 2010 and factors that indicate how brake-specific emissions are expected to change over these time intervals. We applied the factors indicating changes in brake-specific emissions only to exhaust emissions, as both current (and expected future) non-road emission standards apply only to exhaust emissions. Non-exhaust VOC emissions are not currently expected to be controlled. Thus, the growth factors were only applied to these emissions. These factors and the future emission inventories are also shown in Exhibit 5.7.

Exhibit 5.7: Baseline Emissions for Non-Road Engines in Maricopa County (metric tons/summer day)

	Exhaust VOC	Non-Exhaust VOC	CO	NOx
2 Stroke				
1993	21.4	0.9	52.7	0.7
1996	24.5	1.1	53.6	0.9
1999	20.5	1.2	43.0	1.0
2010	10.0	1.6	19.4	1.3
4 Stroke				
1993	26.4	4.4	464.7	1.2
1996	29.0	4.9	379.7	1.4
1999	23.7	5.4	344.4	2.3
2010	10.1	7.0	278.9	3.5

5.5.3 Baseline emissions of air toxics and their cancer-forming potency

Estimation of air toxic emissions is usually accomplished by multiplying the estimated toxic emissions, in terms of the fraction of total exhaust or non-exhaust VOC emissions, by the exhaust or non-exhaust VOC emissions for that particular fuel. The VOC emission rates reflect the effects of ambient temperature, vehicle mix, I/M program, etc. This cannot be done directly for toxics emissions due to the lack of sufficient emission data.

The baseline VOC emissions are those described in the previous section. We generated the air toxics fractions of VOC for exhaust emissions using both the Complex Model and the Predictive Model in the same situations where they are used in estimating exhaust VOC emissions. We used the Complex Model to estimate the baseline benzene fraction of non-exhaust VOC emissions.

Exhibit 5.8 presents the toxic fractions of VOC emissions for 1996 Maricopa County baseline gasoline and ton/day emission estimates for these toxics.

Exhibit 5.8: Baseline Toxic Emissions in Maricopa County			
	Fraction of Exhaust/Evap VOC	Emissions (metric tons/summer day)	
		Calendar Year 1999	Calendar Year 2010
Predictive Model			
Exhaust benzene	0.032	1.69	1.45
Non-exhaust benzene (Complex Model)	0.011	0.44	0.31
Total Benzene	---	2.13	1.76
Butadiene	0.004	0.19	0.16
Formaldehyde	0.008	0.40	0.35
Acetaldehyde	0.003	0.15	0.13
Complex Model			
Exhaust benzene	0.057	2.94	2.55
Non-exhaust benzene	0.011	0.42	0.30
Total Benzene	---	3.37	2.85
Butadiene	0.012	0.60	0.52
Formaldehyde	0.011	0.58	0.50
Acetaldehyde	0.005	0.25	0.22
POM	0.003	0.17	0.15

5.5.4 Baseline particulate emissions

We estimated baseline particulate emissions using the EPA PART5 model. Inputs to the model were consistent with those used above for MOBILE5a. **Exhibit 5.9** shows the resulting emission factors for particulate matter less than 10 microns in diameter (PM10).

To convert these nationwide emission factors to emissions specific to Maricopa County, we adjusted carbonaceous emissions for the difference between Maricopa County baseline VOC emissions and national average VOC emissions, using the adjustment factors presented in Exhibit 5.3. As PM10 emissions are not the primary focus of this study, we applied the average of the Complex Model and Predictive Model estimates from Exhibit 5.3 to produce a single estimate. We adjusted the direct and indirect sulfate emissions by the ratio of the sulfur contents of Maricopa County baseline gasoline and national average gasoline (161/340). We used the total VMT estimate of 60 million miles per day, as discussed earlier.

Exhibit 5.10 shows our estimates of the baseline PM10 emission factors and PM10 emissions for Maricopa County.

Exhibit 5.9 PM10 Emission Factors for Gasoline-Fueled Vehicles, from PART5 (g/mi)

	1999	**2010**
Carbonaceous Exhaust	0.009	0.005
Direct Sulfate Exhaust	0.008	0.008
Total Exhaust	0.017	0.014
Indirect Sulfate	0.024	0.024
Total Direct and Indirect	0.041	0.038

Exhibit 5.10: Baseline PM10 Emissions in Maricopa County

	Calendar Year 1999	**Calendar Year 2010**
Baseline PM10 Emission Factors (g/mi)		
Exhaust Carbonaceous	0.009	0.006
Exhaust Sulfate	0.004	0.004
Total Exhaust (or Direct)	0.013	0.010
Indirect Sulfate	0.012	0.012
Total	0.025	0.021
Baseline PM10 Emissions in Maricopa County (metric tons/summer day)		
Exhaust Carbonaceous	0.56	0.43
Exhaust Sulfate	0.24	0.31
Total Exhaust (or Direct)	0.79	0.74
Indirect Sulfate	0.71	0.91
Total	1.51	1.65

6. RESULTS AND FINDINGS REGARDING THE FUEL FORMULATION OPTIONS

This section presents the primary results and findings of our analysis of the fuel formulation options described in Section 1. The discussion is in six parts:

1. Interpreting the quantitative results
2. Results and findings of the *distribution* analysis
3. Results and findings of the *refining* analysis
4. Results and findings of the *emissions* analysis
5. Estimated *cost-effectiveness* of the various options (with respect to VOC emissions)
6. Findings with respect to associated issues (including vehicle performance, regulatory and enforcement considerations, and impacts on areas outside Maricopa County)

The second, third, and fourth parts lay out the quantitative results of our analysis, regarding, respectively, the gasoline distribution system, the refining sector, and vehicle emissions in Maricopa County. The fifth ties the quantitative results together, in terms of the cost-effectiveness ($/ton of VOC emissions reduction) associated with the various options. The last part addresses various issues associated with the fuel formulation options.

6.1 Interpreting the Quantitative Results of the Analysis

We think it essential, before presenting quantitative results, to briefly discuss the nature and proper use of results from analytical studies such as this one. One should have modest expectations about the precision of these results or the likelihood that they "predict" future conditions. Rather, one should view them as reliable and robust indicators of the relative merits of the various options, with respect to the magnitude of their relative costs, benefits, and cost-effectiveness.

This analysis points to the future: 1999 and 2010. There are no facts about the future. So, analysts must make assumptions about future conditions -- crude oil prices, oxygenate prices, gasoline demand, air quality, vehicle miles traveled, vehicle fleet configurations, and a host of other technical and economic factors. Different sets of assumptions lead to different absolute results. For example, the most important determinant of the cost of producing gasoline is the price of crude oil. (Need we say more?)

Our mathematical models are very good, but like all models, they are approximations of certain parts of the real world. Even if we had "perfect" assumptions going in, the results coming out would not be perfect predictors of the future.

In addition, with the same set of assumptions and the same models, the results of an analysis can depend on the details of the methodology and on the analysts' skill and judgement.

BUT. . .

Rigorous quantitatve analysis is the best method available for assessing complex policy issues, especially those involving the interplay of technical and economic driving forces. More importantly, in such situations, rigorous analysis can yield reliable and robust assessments of the relative merits of different policy options.

That's because analyses such as this one give consistent treatment to all the options under consideration and focus on comparative (or relative) results -- similarities and differences between options -- rather than on absolute results or forecasts. Experience shows that the important differences between options and the important (qualitative) characteristics of individual options usually survive changes in primary assumptions.

> Thus, even if the price of crude oil were to double, the rank ordering of the various fuel formulation options with respect to incremental refining costs would likely not change (even though the absolute cost of gasoline production would increase a lot).

So, the results of this study should be viewed as indicators of the relative costs and merits of the various fuel formulation options (and not as precise assertions of costs or benefits). For example, as this section shows, the federal RFG options are more costly than the low RVP option but deliver more VOC reduction; the California RFG option is the most costly, delivers the most VOC reduction, but also delivers NOx reduction that may or not be desirable; and so on. Most of the robust findings of this study are to be found in the cost-effectiveness summary (shown in the Executive Summary and in Section 6.5).

In a study such as this one, it's better to be approximately right than precisely wrong. With all humility, we think the results of this study are approximately right.

6.2 The Gasoline Distribution System

Analysis of the gasoline distribution system (encompassing the refineries, the SFPP South Pipeline System, and the local bulk terminals) leads to these findings:

? The gasoline distribution system is now supplying to Maricopa County, in routine operations, special gasolines -- in particular, gasolines meeting Maricopa County standards, as opposed to State-wide standards (defined in Section 2.1).

? In general, therefore, the existing distribution system has the capability to deliver the required volumes of special Maricopa County gasolines meeting any of the proposed standards (or indeed other standards, whether property-based or performance-based).

? However, under certain circumstances, the distribution system *might* experience a transient capacity pinch after adoption of a new gasoline standard for Maricopa County. The capacity pinch could occur if (1) one or more of the East refiners were to abandon the Maricopa County market and (2) the gasoline volumes they now supply had to be replaced from Los Angeles.

This second condition would *not* exist if and when the Diamond Shamrock refinery in West Texas were to enter the Maricopa County market, the Longhorn Pipeline were to be built (connecting the U.S. Gulf Coast refineries to the SFPP East pipeline), and/or the Maricopa County refinery were to be built.

? The differences between the Maricopa County and State-wide gasoline standards lead to spill-over and local give-away of excess quality (described in Section 3.5) in Maricopa County and in other areas (some as far away as Las Vegas). For the gasoline volumes involved, we estimate the cost of quality give-away in current operations to be approximately:

Summer season	**0.2 ¢/gal**	**$ 3 MM/season**
Winter season	**0.4-0.6 ¢/gal**	**$ 6- 9 MM/season**
Year-round	**0.3-0.4 ¢/gal**	**$ 9-12 MM/year**

The allocation of these costs -- refiners vs. consumers, inside vs. outside Maricopa County -- is difficult, if not impossible, to determine.

? Each 1 ¢/gal increase in the incremental cost of producing Maricopa County gasoline in the Summer season would increase the cost of quality give-away by about $2 MM/year.

? Eliminating quality give-away would entail full segregation of Maricopa County gasolines, regular and premium, from the refinery to the rack. ARCO Products and Texaco Refining & Marketing appear to segregate their Maricopa County regular gasoline (but not premium gasoline) now. The SFPP pipeline system is capable of segregating Maricopa County gasoline now. But for the other elements of the distribution system, achieving full segregation would require capital investment (for tankage, blending facilities, and inventory) and operational changes at the refinery, pipeline, and bulk terminal levels.

? We estimate that achieving full segregation of Maricopa County gasoline would call for system-wide investment in the range of **$28 - $45 MM**. The annual capital recovery charges for this range of investments would be about **$7 - $11 MM/year**.

? This estimated range of annual capital charges is about the same as the estimated range of annual costs of quality give-away (indicated above). That is, the distribution system as a whole appears close to having an economic incentive to reduce or eliminate excess quality in the system, independent of any new gasoline standards for Maricopa County.

? Any new gasoline standard for Maricopa County that led to incremental give-away costs in excess of about $2 MM/year (corresponding to an incremental refining cost of about 1 ¢/gal, as indicated above) likely would trigger the capital investments needed to reduce or eliminate quality give-away.

Should these investments be made, the incremental cost of quality give-away assignable to the new gasoline standard would be the *difference* between (1) the current costs of quality give-away (. $9-12 MM/year) and (2) the annual capital recovery charges for the investments to abate quality give-away (. $7-11 MM/year). This difference would be in the range of **$0-2 MM/year**, regardless of the gasoline standard involved.

This range of distribution costs is small relative to the refining and fuel economy costs associated with the various fuel formulation options (as indicated in Section 6.5).

6.3 The Refining Sector

Exhibits 6.1 and 6.2 show the primary results of the refining analysis. **Appendix E** contains more detailed and extensive results, for each of the three notional refineries

Exhibit 6.1 summarizes the refining economics of the fuel formulation options considered. For each of the three refining aggregates considered, it shows the estimated incremental refining cost (¢/gal), the aggregate capital investment required ($MM), and the fuel economy loss (%) associated with each of the fuel formulation options.

The incremental refining costs and the fuel economy losses shown in Exhibit 6.1 are relative to those of the baseline gasoline, whose average properties are shown in Exhibit 2.1.

The refinery investment requirements shown in Exhibit 6.1 apply to the indicated refining *aggregates*, not to the notional refineries modeled in the analysis. That is, we scaled up the computed investment requirement for each notional refinery to the entire refining aggregate that it represented.

Exhibit 6.2 summarizes the effects of the fuel formulation options on Maricopa County. For each fuel formulation option considered, the exhibit shows the weighted average incremental cost (total), as seen in Maricopa County, and the weighted average CM properties of the gasoline.

Exhibit 6.1: summary of Refining Economics
By Fuel Formulation Option and Refining Aggregate

Measure	Fuel Formulation Option						
	Federal RFG			California		Low	10% VOC
	Phase 1	Phase 1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
East Refineries							
Incremental Refining Cost (¢/gal)	4.7	4.8	8.0	13.8	5.1	0.3	5.7
Aggregate Capital Investment ($MM)	$5.3	$5.6	$19.6	$31.8	$13.5	-	$5.1
Fuel Economy Loss (%)	3.5%	3.3%	3.2%	4.7%	-0.3%	-0.3%	1.9%
West Refineries							
Incremental Refining Cost (¢/gal)	3.3	3.4	4.0	10.6	0.8	0.2	4.2
Aggregate Capital Investment ($MM)	-	-	$3.7	$10.4	-	-	$2.2
Fuel Economy Loss (%)	2.8%	2.8%	3.3%	4.2%	0.4%	-0.2%	1.6%
Northwest Refineries							
Incremental Refining Cost (¢/gal)	2.9	3.1	3.0	4.6	0.1	0.5	1.3
Aggregate Capital Investment ($MM)	-	-	-	-	-	-	-
Fuel Economy Loss (%)	3.7%	3.8%	3.7%	4.1%	0.1%	-0.3%	1.8%

6.1: Average Incremental Costs and Properties of the Maricopa County Gasoline Pool, by Fuel Formulation Option*

Measure	Current	Fuel Formulation Option						
		Federal RFG			California		Low	10% VOC
		Phase 1	Phase 1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Economics								
Incremental Refining Cost (¢/gal)		3.7	3.8	5.1	11.5	2.0	0.2	4.6
Aggregate Capital Investment ($MM)		$5.3	$5.6	$23.3	$42.1	$13.5	-	$7.4
Fuel Economy Loss (%)		3.0%	2.9%	3.3%	4.4%	0.2%	-0.2%	1.7%
Gasoline Properties								
RVP (psi)	6.7	7.1	6.7	6.6	6.7	6.7	6.2	6.5
Oxygen (wt%)	0.0	2.1	2.1	2.1	2.1	0.0	0.0	0.7
Aromatics (vol%)	35.3	31.1	31.3	27.6	20.4	35.3	35.9	30.3
Benzene (vol%)	1.27	0.95	0.95	0.95	0.73	1.41	1.20	1.46
Olefins (vol%)	10.2	10.7	10.7	9.8	3.1	10.5	10.2	10.2
Sulfur (ppm)	168.4	140.4	140.4	112.4	30.0	97.3	168.4	150.9
T50**	*227.6*	207.7	203.9	203.8	193.9	217.6	*227.1*	203.4
T90**	*334.4*	331.5	332.5	317.6	293.8	333.5	*337.3*	304.5
E200	37.3	46.1	48.0	48.1	52.9	41.3	37.4	48.2
E300	79.9	82.6	82.3	85.6	90.8	82.1	79.3	88.5
Energy Den. (MMbtu/b)	5.28	5.12	5.13	5.11	5.05	5.27	5.29	5.19

* Based on results of ARMs runs.

** Based on EPA formulas:

T50 = (147.91 - E200) / 0.49

T90 = (155.47 - E300) / 0.22

Note: Italics indicate that the T50 or T90 for the West refinery group was estimated using ARMS generated distillation curves, rather than EPA's formulas.

Exhibits E.1.1 - E.1.4, E.2.1 - E.2.4, and E.3.1 - E.3.4 (in Appendix E) provide detailed results of the refining analysis for, respectively, the East, West, and Northwest notional refineries. Each of these exhibits covers all of the fuel formulation options considered. The contents of the exhibits are as follows.

- ? Exhibits E.x.1: Crude oil inputs, process unit utilization, new capacity additions, operating indices, and key unit charge rates for the notional refinery
- ? Exhibits E.x.2: Average properties and composition of Maricopa County gasoline and other gasolines produced by the notional refinery
- ? Exhibits E.x.3: Changes in the notional refinery's costs and revenues (with respect to the reference case)
- ? Exhibits E.x.4: Changes in the notional refinery's crude oil and other inputs and product outputs (with respect to the reference case)

Here, **x** denotes the numbers 1, 2, or 3, corresponding to the **East**, **West**, and **Northwest** notional refineries, respectively.

In all of these exhibits, we use the abbreviated names for the fuel formulation options, defined in Section 1.2. For brevity, we also use these abbreviations in the discussion that follows.

6.3.1 Refining economics

Examination of the results shown in the various exhibits leads to the following findings.

- ? The East refining aggregate incurs the highest incremental costs to produce the various fuel formulation options; the Northwest (remote) refining aggregate incurs the lowest incremental costs.

  In general, the East refining aggregate shows higher costs than the West refining aggregate because the East refineries are less "complex" (i.e., have less gasoline-making capability per barrel of crude) than the West refineries. The East refineries would require more investment than the others to produce gasolines offering significant emissions reductions.

  The West refining aggregate shows relatively high costs for **California RFG** because this option involves increasing overall production of California RFG near the margin, and therefore would incur high marginal costs of production.

If, in fact, a California that does not now produce a significant volume of California RFG were to produce California RFG for Maricopa County, it might incur incremental costs lower than indicated in Exhibit 6.1 for the **California RFG** option. The specification of the West notional refinery precluded consideration of that possibility in this study.

The Northwest (remote refinery) costs do not include the cost of transportation from the remote location to the nearest connection with the SFPP pipeline system; that is, tanker shipments to Los Angeles or pipeline shipments to El Paso. (These costs would be about 3 - 6 ¢/gal.)

? The refining aggregates considered would have significantly different requirements for capital investment to produce the fuel formulation options.

-- The East refiners would have the largest investment requirement and would have to make some investments for all of the fuel formulation options.

-- The West refiners would have no investment requirement -- except for **California RFG**, for which they would have to invest to upgrade much of their remaining conventional gasoline out-turn to California RFG. In particular, the West refiners could produce **Phase 1 RFG** without capital investment -- even for benzene control.[1]

-- The Northwest (remote) refiners would have no investment requirement for any of the options -- even **California RFG**. This finding follows from our assumption in configuring the Northwest notional refinery that only a small portion of its total gasoline production would be to Maricopa County standards.

In most cases, the indicated investments reflect expansions of existing process units or construction of secondary facilities (such as fractionators). In practice, refiners might choose not to make these investments, but rather modify operating procedures, use spare capacity elsewhere, or purchase blendstocks.

[1] The AAMA gasoline surveys for both 1995 and 1996 showed Maricopa County gasoline having a benzene content of 1.1 wt.% (vs. the federal RFG standard of 0.95 wt.%). Maricopa County gasoline produced by the East refineries almost surely has benzene content *higher than* 1.1 wt.%, because the East refineries have neither the requirements nor the facilities for benzene control. So, Maricopa County gasoline produced by the West refineries is likely to have benzene content *less than* 1.1 wt.% right now. MTBE blending (to meet the federal RFG oxygen standard) would in itself lower that benzene content by about 10% (e.g., from < 1.1 wt.% to < 1 wt.%).

? The Northwest (remote) refining aggregate shows the lowest incremental costs across the board because (as noted above) only a small portion of its gasoline production would be to Maricopa County standards. Therefore, such production would enjoy the economic benefits of the refiners' flexibility in blending multiple gasoline pools, low marginal costs of production, and no capital recovery charges.

As Exhibit 6.1 indicates, the Northwest refining aggregate -- or, more accurately, remote refineries with suitable capabilities and location -- would have a particularly strong cost advantage in producing California RFG for Maricopa County.

? In general, of the fuel formulation options, **California RFG** would have the highest incremental cost. **Low RVP** gasoline would have the lowest incremental refining cost. (As discussed in Section 4.6.4, we assumed that Maricopa County gasoline would be fully segregated under the various fuel formulation options. With such segregation, refineries could produce low RVP gasoline for Maricopa County without increasing pool average RVP.)

? The **Phase 1 RFG**, **Phase 2 RFG**, and **10% VOC Reduction** options show roughly comparable incremental costs, but they are different gasolines. Federal Phase 1 RFG is produced to a property-based standard; Phase 2 RFG will be produced to a hybrid property- and performance-based standard. The 10% VOC Reduction option would be produced to a pure performance-based standard (involving VOC and NOx emissions, as discussed in Section 1.3).

-- Most of the incremental refining cost for **Phase 1 RFG** is accounted for by the oxygen content and benzene content standards (shown in Exhibit 1.1).

-- The additional cost increment for **Phase 2 RFG** is accounted for mainly by sulfur control, which (under the Complex Model) is the primary means of achieving the Phase 2 reduction in NOx emissions.

-- Most of the incremental refining cost for **10% VOC Reduction** is accounted for by E200 and E300 control (accomplished in part by oxygenate blending).[2]

6.3.2 Fuel economy

[2] Our analysis indicates that oxygenate blending would be the method of choice for producing Maricopa County gasoline in the **California RFG** option, given the "quality hold" requirement for the conventional gasoline produced in conjunction with Maricopa County gasoline. We recognize that the California RFG program requires oxygenate blending only for RFG sold in the federally mandated areas.

All of of the fuel formulation options except **Low RVP** incur a loss in fuel economy, or mileage (miles/gal). The mileage losses are social costs associated with the various fuel formulation options. As Exhibit 6.2 shows, the mileage losses are significant contributors to the total social cost of the various fuel formulation options.

As discussed in Section 4.6.3, physical considerations dictate that a gasoline's energy density -- and hence fuel economy -- decreases with increasing oxygen content, increasing distillation values (i.e., E200 and E300), and increasing RVP. The ARMS model captures all of these effects. We computed the mileage losses shown in Exhibit 6.1 from energy density values produced by ARMS for each fuel formulation option, according to the formula shown in Section 4.6.3.

The primary cause of the mileage losses shown in Exhibit 6.1 is oxygenate blending.[3] However, the mileage losses shown in Exhibit 6.1 are somewhat larger than those usually cited for oxygenate blending. These high values follow from the fact that the baseline gasoline is unusually heavy (as indicated by the distillation and DI values in Exhibit 2.1). Because it is unusually heavy, it has unusually high energy density (˜5.3 MM BTU/Bbl vs. ˜5.2 MM BTU/Bbl for a typical gasoline pool produced in PADD 3). Hence, the oxygenate blending called for by many of the fuel formulation options leads to an unusually large reduction in energy density.

6.3.3 Incremental Costs (to Maricopa County) and Gasoline Quality

The incremental costs and gasoline properties shown in Exhibit 6.2 are volume weighted averages of contributions from the various refining aggregates. To calculate these weighted averages, we used the following weighting factors.

?	East:	0.28
?	West:	0.72
?	Northwest:	0

The weights for the East and West refining aggregates are in proportion to the volumes of gasoline shipped to Phoenix through the East and West pipelines in 1995 (shown in Exhibit 3.2). The zero weight for the Northwest reflects the position (stated in Section 4.2) that the Northwest notional refinery represents remote refiners who can supply gasoline or blendstocks to the Los Angeles refining center. Some gasoline from these refineries no doubt reaches Maricopa County, and the volume of such supplies may increase over time. But estimating the month-to-month and average volumes of these supplies is difficult.

3 Oxygenates have energy densities 25-30% lower than those of conventional blendstocks.

The total incremental costs shown in Exhibit 6.2 are simply the sum of the corresponding incremental refining costs and the mileage losses.

The volume weighted gasoline properties shown in Exhibit 6.2 are *average* properties (in the gasoline blending sense). That is, they correspond to averaging rather than per-gallon standards.

These gasoline properties were direct input to the emissions analysis (discussed in Section 5). The estimated emissions reductions shown in Section 6.3 apply to Maricopa County gasoline pools with these average properties.

6.3.4 Applicability to the target years: 1999 and 2010

Now, we turn to the question of timing. That is, for what period do the results of the refining analysis apply? In particular, which of the various fuel formulation options can be implemented in 1999 -- at least from the standpoint of the refining sector?

Refinery LP models, such as ARMS, represent refining operations on an average day in a specified time period. Hence, the incremental refining costs shown in Exhibit 6.1 apply to "steady state" operations. By "steady state", we mean normal technical operations and business arrangements after refiners had invested in new capacity and changed operations as needed to supply gasoline to the new Maricopa County standard and to meet demand growth over time.

Clearly, 2010 would qualify as a steady state year (barring establishment of new environmental standards on refined products in the intervening years or some wrenching change in market structure). The incremental refining costs and other results summarized in the exhibits should be viewed as reflecting operations in 2010.

On the other hand, 1999 might not be a steady state year, and the indicated results might, therefore, not be representative of 1999 operations.

Depending on the regulatory timetable, refiners might not have enough lead time to install new capacity, change technical operations, adapt business relationships, and establish compliance procedures prior to the effective date of the new gasoline standard. If not, the refining sector would go through some transient period before reaching a new steady state. The likelihood and length of a transient period would depend on the effective date of the new gasoline standard. The sooner it takes effect, the more likely and the longer the resulting transient.

The incremental refining costs estimated in this analysis would not necessarily reflect overall refining economics bearing on Maricopa County in a transient period. A transient period would be marked by continuing changes in the sourcing of some of the gasoline supplied to Maricopa County and, possibly, changes in the set of refiners supplying gasoline to the county. For example, a transient might lead refineries in West Texas (e.g., Diamond Shamrock) and in the U.S. Gulf Coast to supply gasoline to Maricopa County. Similarly, the Maricopa Refinery might be built in this period. Our analysis did not encompass these possibilities, for the reasons stated in Section 4.2.

(Estimating the refining economics and the costs of supplying Maricopa County during a transient period is well beyond the scope of this project and indeed beyond the capabilities of existing analytical methods.)

In summary, the results of the refining analysis are likely to be applicable to 2010 but may or may not be applicable to 1999. For 1999, the issue turns on whether or not the refining sector would have enough lead time to reach steady state by then.

The refinery investment requirements shown in Exhibit 6.1 suggest an answer. Fuel formulation options that call for significant investments probably could not be implemented by all refiners by Summer 1999. In particular, the East and West refining aggregates might not be able to comply with the **California RFG** option by 1999. Should 1999 witness any shortfalls in supply from the East and West refiners, these shortfalls would be met by supplies from remote refiners: e.g., from the Northwest, the San Francisco Bay area, the U.S. Gulf Coast, or West Texas.

6.4 Vehicle Emissions

Exhibits 6.3 through 6.8 summarize the results of the emissions analysis.

Exhibit 6.3 presents the estimates of total VOC and NOx emissions from gasoline-fueled sources (in metric tons/day) in Maricopa County, for each fuel formulation option.

Regarding VOC emission impacts, in most cases, 60-80% of the emission reduction is from on-road vehicles, with 20-40% of the emission benefits coming from non-road engines. **California RFG** provides the most benefit using either the Predictive Model or the Complex Model (10-16 metric tons/day), followed by federal **Phase 2 RFG** and **10% VOC Reduction**. **Phase 1 RFG & 7 RVP** falls in the middle of the pack, followed by the remaining three fuel formulation options, whose order depends on the time period and the model used. **Low RVP** provides the smallest VOC emission benefit, with increases in exhaust VOC emissions (particularly when the Predictive Model is used) mitigating the reductions in non-exhaust VOC emissions.

Regarding NOx emission impacts, in most cases, essentially all of the emission benefit is from on-road vehicles. Non-road, gasoline-fueled engines produce very little NOx emissions. **California RFG** again provides the most benefit using either emission model (8-9 metric tons/day), roughly 3-4 times as much NOx control as any other fuel option. **Phase 2 RFG** and

GAPEP produce small NOx benefits, 1-3 metric tons per day. None of the other fuel formulation options produce significant reductions in NOx emissions. The differences between the two emission models are much smaller for NOx emissions than for VOC emissions.

Exhibit 6.4 presents the estimated CO emissions (in metric tons/day) associated with the fuel formulation options. Again, **California RFG** provides the largest reduction (150-200 metric tons/day), followed by **Phase 2 RFG** (90-140 metric tons/day) and **Phase 1 RFG & 7 RVP** (110-140 metric tons/day).

The California Air Resources Board (CARB) uses an ozone reactivity factor for CO emissions that is roughly 40-60 times lower than that for VOC emissions. Thus, for example, the CO reduction for **California RFG** is roughly equivalent to 2.5-5 tons/day of VOC, which is significant relative to that fuel's direct VOC benefit of 10-16 tons/day.

Exhibit 6.5 presents the exhaust PM10 emissions (in metric tons/day) associated with each fuel formulation option. These estimates include only the effect of fuel quality on direct emissions of carbonaceous and sulfate PM. **California RFG** provides the most benefit using either model (roughly 1 metric ton/day), followed by **Phase 2 RFG** and **GAPEP**. The other options, except for **Low RVP**, provide smaller PM10 benefits.

Exhibit 6.5 also shows the directional effect of each fuel formulation option on secondary organic aerosol formation. This effect is a function of T90, aromatic content, and olefin content. **California RFG** improves all three of these factors; **Phase 2 RFG** improves two of them. **10% VOC Reduction** and **Phase 1 RFG** improve one factor. **Low RVP** leads to an increase in T90, so it would tend to increase secondary organic aerosol levels.

Exhibits 6.6A and 6.6B present the air toxic emissions (in metric tons/day) associated with each fuel formulation option. The effect is shown for each toxic pollutant individually and on a benzene-equivalent basis. Again, **California RFG** provides the largest reduction (1-3 metric tons/day benzene equivalent), followed by **Phase 2 RFG** (1-2 metric tons/day benzene equivalent) and **Phase 1 RFG**, with or without 7.0 RVP (0.5-1 metric tons/day benzene equivalent). **10% VOC Reduction** provides a smaller net toxics benefit. **GAPEP** and **Low RVP** provide little benefit or small detriments in this area.

Exhibit 6.7 presents the impact of the fuel formulation options on the ozone-forming potential of VOC and CO emissions. The estimates in Exhibit 6.7 are normalized to the average reactivity of VOC emissions from current Maricopa County gasoline.

Exhibit 6.8 presents the ratio of ozone benefit to VOC benefit for each fuel formulation option. The ozone benefits of all of the options (except for **Low RVP** under the Predictive Model) are higher than the VOC emission benefits. This occurs because these fuels tend to produce greater reductions of the more reactive exhaust VOC emissions than the less reactive non-exhaust VOC emissions. Reductions in CO emissions also tend to add to the projected ozone benefit relative to the VOC emission benefit.

Exhibit 6.3: VOC and NOx Emission Impacts in Maricopa County (metric tons/Summer day)							
	Phase 1 RFG	Phase 1 RFG/ 7.0 RVP	Phase 2 RFG	GAPEP	Low RVP	Calif RFG	10% VOC Reduction
Calendar Year 1999							
Predictive Model							
Onroad Exhaust VOC	-5.4	-6.1	-7.9	-3.5	0.7	-11.6	-7.5
Onroad Non-Exhaust VOC	2.2	0.0	-0.5	0.0	-1.0	0.0	-1.0
Nonroad Exhaust VOC	-4.4	-4.9	-4.8	-1.5	0.1	-3.9	-4.2
Nonroad Non-Exhaust VOC	0.4	0.0	-0.1	0.0	-0.2	0.0	-0.2
Total VOC	-7.2	-11.0	-13.3	-5.0	-0.5	-15.5	-12.9
Onroad NOx	-1.1	-1.1	-2.7	-2.6	0.2	-8.6	-1.1
Nonroad NOx	0.0	0.0	0.0	0.0	0.0	-0.2	0.0
Total NOx	-1.1	-1.1	-2.8	-2.6	0.2	-8.8	-1.2
Complex Model							
Onroad Exhaust VOC	-4.3	-5.3	-7.2	-3.1	-1.2	-8.6	-6.4
Onroad Non-Exhaust VOC	2.2	0.0	-0.5	0.0	-1.0	0.0	-1.0
Nonroad Exhaust VOC	-2.2	-3.3	-4.8	-1.0	0.1	-5.5	-4.4
Nonroad Non-Exhaust VOC	0.4	0.0	-0.1	0.0	-0.2	0.0	-0.2
Total VOC	-3.9	-8.7	-12.5	-4.2	-2.4	-14.1	-12.1
Onroad NOx	-0.4	-0.3	-2.0	-1.3	0.2	-8.1	0.0
Nonroad NOx	0.0	0.0	0.0	0.0	0.0	-0.1	0.0
Total NOx	-0.3	-0.2	-2.0	-1.3	0.2	-8.2	0.0
Calendar Year 2010							
Predictive Model							
Onroad Exhaust VOC	-4.7	-5.4	-7.4	-3.7	0.9	-11.6	-7.3
Onroad Non-Exhaust VOC	1.9	0.0	-0.4	0.0	-0.9	0.0	-0.9
Nonroad Exhaust VOC	-2.0	-2.2	-2.2	-0.7	0.0	-1.8	-1.9
Nonroad Non-Exhaust VOC	0.6	0.0	-0.1	0.0	-0.3	0.0	-0.3
Total VOC	-4.2	-7.6	-10.2	-4.4	-0.3	-13.4	-10.4
Onroad NOx	-1.6	-1.6	-3.0	-3.2	0.1	-8.5	-1.1
Nonroad NOx	0.0	0.1	-0.1	0.0	0.0	-0.4	0.0
Total NOx	-1.5	-1.5	-3.0	-3.2	0.1	-8.9	-1.2
Complex Model							
Onroad Exhaust VOC	-3.7	-4.6	-6.2	-2.7	-1.1	-7.5	-5.6
Onroad Non-Exhaust VOC	1.9	0.0	-0.4	0.0	-0.9	0.0	-0.9
Nonroad Exhaust VOC	-1.0	-1.5	-2.2	-0.5	0.0	-2.5	-2.0
Nonroad Non-Exhaust VOC	0.6	0.0	-0.1	0.0	-0.3	0.0	-0.3
Total VOC	-2.2	-6.1	-9.0	-3.2	-2.2	-10.0	-8.8
Onroad NOx	-0.4	-0.3	-2.2	-1.6	0.1	-8.6	-0.1
Nonroad NOx	0.0	0.0	0.0	0.1	0.0	-0.2	0.0
Total NOx	-0.4	-0.3	-2.2	-1.5	0.2	-8.8	-0.1

Exhibit 6.4: CO Emission Impacts in Maricopa County (metric tons/Summer day)

	Phase 1 RFG	Phase 1 RFG/ 7.0 RVP	Phase 2 RFG	GAPEP	Low RVP	Calif RFG	10% VOC Reduction
Calendar Year 1999							
Onroad CO	-80.5	-77.6	-95.7	-36.5	-13.1	-137.5	-26.4
Nonroad CO	-28.4	-41.0	-47.6	-8.1	-7.3	-60.7	-12.2
Total CO	-108.8	-118.6	-143.3	-44.5	-20.4	-198.3	-38.6
Calendar Year 2010							
Onroad CO	-59.7	-57.6	-71.1	-27.1	-9.8	-102.1	-19.6
Nonroad CO	-21.8	-31.6	-36.6	-6.2	-5.6	-46.8	-9.4
Total CO	-81.6	-89.1	-107.7	-33.3	-15.3	-148.8	-29.0

Exhibit 6.5: PM10 Emission Impacts in Maricopa County

Directly Emitted Carbonaceous and Sulfate Emissions (metric tons/summer day)

Predictive Model							
1999	-0.25	-0.27	-0.40	-0.35	-0.01	-0.76	-0.27
2010	-0.28	-0.30	-0.50	-0.48	0.01	-1.03	-0.29
Complex Model							
1999	-0.22	-0.25	-0.38	-0.34	-0.05	-0.69	-0.24
2010	-0.26	-0.29	-0.47	-0.46	-0.05	-0.93	-0.26
Indirect Carbonaceous *	<	<	<<	---	>	<<<	<

* "<" or ">" means a reduction or increase due to one fuel factor, "<<" means a reduction due to 2 fuel factors, etc.; "---" means no change

Exhibit 6.6A: Toxic Emission Impacts in Maricopa County (metric tons/day)							
	Phase 1 RFG	Phase 1 RFG/ 7.0 RVP	Phase 2 RFG	GAPEP	Low RVP	Calif RFG	10% VOC Reduction
Calendar Year 1999							
Predictive Model							
Exhaust benzene	-0.35	-0.35	-0.48	-0.07	-0.02	-0.80	-0.15
Non-Exhaust Benzene	-0.12	-0.12	-0.12	0.05	-0.02	-0.20	0.04
Total Benzene	-0.47	-0.48	-0.61	-0.02	-0.04	-1.00	-0.12
Butadiene	-0.01	-0.01	-0.02	-0.01	0.01	-0.07	-0.03
Formaldehyde	0.09	0.09	0.10	0.02	0.01	0.14	0.02
Acetaldehyde	0.01	0.01	0.01	0.00	0.00	0.01	-0.01
Benzene Equivalent (ARB Potencies)	-0.48	-0.50	-0.71	-0.06	0.02	-1.36	-0.29
Complex Model							
Exhaust benzene	-0.70	-0.70	-0.84	0.05	-0.21	-1.19	0.12
Non-Exhaust Benzene	-0.12	-0.12	-0.12	0.05	-0.02	-0.20	0.04
Total Benzene	-0.81	-0.82	-0.96	0.10	-0.23	-1.39	0.16
Butadiene	-0.07	-0.08	-0.11	-0.01	0.01	-0.24	-0.10
Formaldehyde	0.06	0.06	0.06	-0.03	0.02	0.14	-0.04
Acetaldehyde	-0.02	-0.02	-0.03	-0.01	-0.01	-0.04	-0.03
POM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzene Equivalent (EPA Potencies)	-1.24	-1.29	-1.59	0.05	-0.19	-2.79	-0.45

Exhibit 6.6B: Toxic Emission Impacts in Maricopa County (metric tons/day)							
	Phase 1 RFG	Phase 1 RFG/ 7.0 RVP	Phase 2 RFG	GAPEP	Low RVP	Calif RFG	10% VOC Reduction
Calendar Year 2010							
Predictive Model							
Exhaust benzene	-0.30	-0.31	-0.43	-0.09	-0.02	-0.73	-0.16
Non-Exhaust Benzene	-0.08	-0.09	-0.09	0.04	-0.01	-0.14	0.02
Total Benzene	-0.38	-0.39	-0.52	-0.06	-0.03	-0.87	-0.14
Butadiene	-0.01	-0.01	-0.02	-0.01	0.01	-0.06	-0.03
Formaldehyde	0.05	0.05	0.05	0.01	0.01	0.05	-0.01
Acetaldehyde	0.01	0.01	0.00	-0.01	0.00	0.00	-0.01
Benzene Equivalent (ARB Potencies)	-0.41	-0.43	-0.62	-0.11	0.01	-1.19	-0.29
Complex Model							
Exhaust benzene	-0.60	-0.61	-0.73	0.04	-0.18	-1.04	0.10
Non-Exhaust Benzene	-0.08	-0.09	-0.09	0.04	-0.01	-0.14	0.02
Total Benzene	-0.68	-0.69	-0.81	0.08	-0.20	-1.17	0.13
Butadiene	-0.06	-0.07	-0.09	-0.01	0.00	-0.21	-0.09
Formaldehyde	0.05	0.05	0.05	-0.02	0.02	0.12	-0.03
Acetaldehyde	-0.02	-0.02	-0.02	-0.01	-0.01	-0.03	-0.02
POM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzene Equivalent (EPA Potencies)	-1.05	-1.10	-1.36	0.04	-0.16	-2.39	-0.40

Exhibit 6.7: Ozone Impacts in Maricopa County (metric tons/day of VOC Equivalent)							
	Phase 1 RFG	Phase 1 RFG/ 7.0 RVP	Phase 2 RFG	GAPEP	Low RVP	Calif RFG	10% VOC Reduction
Calendar Ye ar 1999							
Predictive Model							
Exhaust VOC	-11.6	-13.0	-15.1	-5.9	0.9	-18.4	-13.9
Non-Exhaust VOC	1.7	0.0	-0.4	0.0	-0.8	0.0	-0.8
CO	-2.0	-2.2	-2.6	-0.8	-0.4	-3.6	-0.7
Total	-11.8	-15.2	-18.1	-6.8	-0.3	-22.0	-15.4
Complex Model							
Exhaust VOC	-7.7	-10.3	-14.2	-5.0	-1.4	-16.8	-12.9
Non-Exhaust VOC	1.7	0.0	-0.4	0.0	-0.8	0.0	-0.8
CO	-2.0	-2.2	-2.6	-0.8	-0.4	-3.6	-0.7
Total	-7.9	-12.4	-17.2	-5.8	-2.6	-20.4	-14.4
Calendar Year 2010							
Predictive Model							
Exhaust VOC	-8.0	-9.0	-11.4	-5.2	1.1	-15.9	-10.9
Non-Exhaust VOC	1.7	0.0	-0.4	0.0	-0.8	0.0	-0.8
CO	-1.5	-1.6	-2.0	-0.6	-0.3	-2.7	-0.5
Total	-7.8	-10.7	-13.8	-5.8	0.0	-18.6	-12.3
Complex Model							
Exhaust VOC	-5.6	-7.3	-10.0	-3.8	-1.2	-11.9	-9.0
Non-Exhaust VOC	1.7	0.0	-0.4	0.0	-0.8	0.0	-0.8
CO	-1.5	-1.6	-2.0	-0.6	-0.3	-2.7	-0.5
Total	-5.4	-8.9	-12.4	-4.4	-2.3	-14.6	-10.4

* Assumes ozone reactivities of 3.5 for exhaust VOC, 2.0 for non-exhaust VOC and 0.054 for CO.

Exhibit 6.8: Ratio of Ozone Impact to VOC Impact							
	Phase 1 RFG	Phase 1 RFG/ 7.0 RVP	Phase 2 RFG	GAPEP	Low RVP	Calif RFG	10% VOC Reduction
Calendar Year 1999							
Predictive Model	1.64	1.38	1.36	1.35	0.66	1.42	1.19
Complex Model	2.03	1.44	1.37	1.38	1.08	1.44	1.19
Calendar Year 2010							
Predictive Model	1.85	1.40	1.35	1.33	-0.08	1.39	1.18
Complex Model	2.46	1.46	1.37	1.38	1.04	1.46	1.18

Most of the fuel formulation options produce roughly 40% more ozone benefits than VOC emission benefits (i.e., a ratio of 1.4 in Exhibit 6.8). **Phase 1 RFG** shows a greater improvement (64-146%, or a ratio of 1.64-2.46), because non-exhaust VOC emissions are actually projected to rise with this fuel. This increase receives less weighting in the ozone calculation than in the VOC calculation. **10% VOC Reduction** shows less than average sensitivity (only a 20% increase in ozone benefit relative to VOC emission benefit) because of its slightly greater reliance on non-exhaust VOC emission reductions. **Low RVP** actually produces lower ozone benefits than VOC emission benefits in some cases because of its even greater reliance on non-exhaust VOC emission reductions.

6.5 Cost Effectiveness of the Fuel Formulation Options

6.5.1 Results

Exhibit 6.9 shows the estimated cost-effectiveness of the fuel formulation options considered, expressed in $ per ton of VOC emission reduction (**$/ton VOC**). The exhibit contains separate estimates of cost-effectiveness for 1999 and 2010.

This exhibit summarizes the primary results of the entire study.

In line with the discussion in Section 6.1, we recommend viewing the cost-effectiveness estimates as robust indicators of the relative costs and merits of the various fuel formulation options, not as precise assertions of costs or benefits. They offer a means of rank ordering the various fuel formulation options, at least with respect to the technical and economic factors considered in this study.

Exhibit 6.9: Cost-Effectiveness, Refining Mileage Costs, and VOC, NOx, and CO Emission Reductions, by Fuel Formulation Option – Summer Season

		Fuel Formulation Option						
	Baseline	Federal RFG			California		Low	10% VOC
Measure	Emissions	Phase 1	Phase 1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Cost-effectiveness ($M/ton of VOCs)								
1999								
Complex Model		$63	$28	$25	$41	$18	-	$18
Predictive Model		$34	$22	$23	$37	$15	-	$17
2010								
Complex Model		$215	$78	$63	$98	$33	-	$43
Predictive Model		$113	$62	$56	$73	$24	-	$36
Refining and Mileage Costs (¢/gal)								
Incremental Refining Cost		3.7	3.8	5.1	11.5	2.0	0.2	4.6
Cost of Mileage Loss*		3.7	3.7	4.2	5.8	0.2	-0.2	2.1
Total Unit Cost		**7.4**	**7.5**	**9.3**	**17.3**	**2.3**	**-0.0**	**6.7**
Maricopa County Cost ($M/day)**								
1999		$245	$247	$307	$571	$74	-	$223
2010		$474	$474	$571	$981	$105	-	$376
Vehicle Emission Reductions (tons/day)								
VOCs								
1999								
Complex Model	140.4	3.9	8.7	12.5	14.1	4.2	2.4	12.1
Predictive Model	140.5	7.2	11.0	13.3	15.5	5.0	0.5	12.9
2010								
Complex Model	100.1	2.2	6.1	9.0	10.0	3.2	2.2	8.8
Predictive Model	99.8	4.2	7.6	10.2	13.4	4.4	0.3	10.4
NOx								
1999								
Complex Model	96.6	0.3	0.2	2.0	8.2	1.3	-0.2	0.0
Predictive Model	95.2	1.1	1.1	2.8	8.8	2.6	-0.2	1.2
2010								
Complex Model	97.7	0.4	0.3	2.2	8.8	1.5	-0.2	0.1
Predictive Model	96.3	1.5	1.5	3.0	8.9	3.2	-0.1	1.2
CO								
1999	1048.5	108.8	113.6	143.3	198.3	44.5	20.4	38.6
2010	789.0	81.6	89.1	107.7	148.8	33.3	15.3	29.0

Note: All costs, emission reductions, and cost-effectiveness measures are for the summer season only.

* The cost of mileage loss is estimated as the percent loss in fuel economy times the summer retail price for gasoline (about $1.40/gallon), minus the Arizona State gasoline tax (18 ¢/gal), and plus the incremental refining cost of each fuel formulation option.

** Assumes gasoline sales in Maricopa County in 1999 and 2010 are 12% and 44% higher, respectively, than sales in 1995 of about 70,200 bbl/d.

Sources:

Costs and Mileage Loss: Exhibit 6.2

Emission Baselines and Reductions: Exhibits 5.6, 5.7, and 6.2.

Exhibit 6.9 shows that

? The **Task Force** and **Low RVP** options have low cost-effectiveness values, but offer relatively little in the way of VOC emission reductions.

? The federal RFG options, **Phase 1 RFG & 7.0 RVP** and **Phase 2 RFG**, and the **10% VOC Reduction** option offer the strongest combinations of VOC emission reductions and cost-effectiveness -- before accounting for the possible effects of the accompanying NOx reductions with the federal RFG options.

? The **California RFG** option offers the largest VOC emission reduction, but with cost-effectiveness inferior to the federal RFG and 10% VOC reduction options -- and again without accounting for the possible effects of the accompanying NOx reductions with California RFG.

? The choice of emission modeling methodology -- Complex Model vs. Complex/Predictive Models -- influences the magnitude of the estimated VOC emission reductions and the estimated cost effectiveness of the various options, but not the rank ordering of the various fuel formulation options with respect to these measures.

? The cost-effectiveness of each fuel formulation option decreases from 1999 to 2010. As time goes on, improvements in vehicle emission control technology and changes in the distribution of model years in the vehicle fleet progressively reduce engine exhaust emissions (with fuel properties constant). These trends reduce the magnitude of emissions reductions, in tons per day, that improvements in gasoline properties can yield.

? CO reductions could be equivalent to an additional 1-4 tons/day of VOC reductions, depending on the fuel formulation option. These estimated reductions follow from the CO emission reductions shown in Exhibit 6.4 and the CARB reactivity factor for CO (noted in Section 6.4). Fuel formulaton options involving oxygenate blending show the largest reductions in CO emissions.

This last point indicates that clarifying the effect of CO emissions on ozone levels in Maricopa County in the UAM modeling work (along with the effect of NOx emissions) would sharpen future assessments of various fuel formulation options for ozone control.

6.5.2 Methodology

Our methodology for developing the estimates shown in Exhibit 6.9 was as follows:

? For each fuel formulation option, we computed the associated *cost* (in $M/day) as the sum of the total incremental refining cost, the total fuel economy loss, and the total incremental distribution cost.

-- The *total incremental refining cost* is the average incremental refining cost -- shown in Exhibit 6.2 -- multiplied by the average daily consumption of gasoline in Maricopa County (Summer season) -- drawn from Exhibits 3.1 and 3.2.

-- The *total fuel economy loss* is the average mileage loss -- shown in Exhibit 6.2 -- multiplied by the average daily consumption of gasoline in Maricopa County (Summer season) multiplied by the net retail price of gasoline. (For purposes of this analysis, the net retail price of gasoline is the retail price (volume averaged over all grades) minus the state tax plus the average incremental refining cost, as defined in Section 4.6.3).

-- The total incremental distribution cost is zero, pursuant to the discussions in Section 3.5 and Section 6.2.

? For each fuel formulation option, year of interest, and modeling methodolgy, we took the associated *VOC emission reduction* (in ton VOC/day) directly from the results of the emissions analysis, shown in Exhibit 6.3.

? For all fuel formulation options and both years of interest, we calculated gasoline consumption in Maricopa County on the basis of 3% annual growth in consumption. This growth rate reflects (1) 3% annual growth in vehicle miles traveled and (2) no change in the average fuel economy of the vehicle fleet.

6.6 Other Considerations

6.6.1 Vehicle performance

As indicated in Section 6.2, all of the fuel formulation options except **Low RVP** incur a mileage loss with respect to the baseline gasoline. These losses are costs to Maricopa County associated with the various fuel formulation options.

The mileage losses are the result of the gasoline barrel becoming "lighter" (i.e., less dense), as a result of oxygenate addition and steps to increase E200 and E300 values (which leads to reduced VOC emissions in the Complex Model).

In general, as the gasoline barrel becomes lighter, DI decreases correspondingly. So, the DI of the various fuel formulation options, except **Low RVP**, would be lower than that of the baseline gasoline (though we did not calculate DI values for the fuel formulation options).

6.6.2 Effects on other areas of Arizona

The results of this study indicate little or no impact of the various fuel formulation options on other areas of Arizona.

As noted in Section 6.2, the gasoline distribution system serving Maricopa County may now have (or be close to having) an economic incentive to abate the costs of spill-over and local quality give-away that the system now incurs. Any new gasoline standard for Maricopa County would increase that incentive.

Moreover, the Subcommittee has adopted the position that Maricopa County gasoline would be produced on a "quality hold" basis (as defined in Section 4.6.1). On that basis, areas in Arizona outside Maricopa County would experience no decrease in the emissions performance of the gasoline that they received, as a result of the adoption of a new, more stringent gasoline standard for Maricopa County.

6.6.3 Effects on areas outside of Arizona

Outside of Arizona, the primary effect of the various fuel formulation options would be to increase the marginal cost of producing gasolines for sale in the other areas supplied by the refineries that supply Maricopa County (especially if the gasolines were produced on a quality-hold basis).

For example, if the West refineries that now produce California RFG for in-state consumption were to produce California RFG for Maricopa County, their marginal cost of producing California RFG would increase. That increase in marginal cost could be felt by all consumers of California RFG, not just those in Maricopa County.

Superficially, this techno-economic phenomenon may seem not to affect Arizona. But it does. Increases in the marginal cost of gasolines produced by the refineries supplying Maricopa County could limit the volume of gasoline that these refiners (both local and remote) were willing to supply to Maricopa County standards.

6.6.4 Performance-based standards

This study addressed the issue of performance-based standards by considering a **10% VOC Reduction** option. Its refining economics and emissions performance seem attractive.

However, time constraints did not permit anything more than this initial exploration of performance-based standards. It would be desirable to analyze performance-based standards in more depth in the near future.

In particular, once the results of the UAM modeling are available, further analysis could delineate the VOC reduction function described in Section 1.3 for one or more levels of change in NOx emissions (as might be indicated by the UAM modeling). At the same time, the regulatory issues associated with performance-based standards could be identified and analyzed.

Such analysis could identify a performance-based standard for Maricopa County that would (1) yield substantial VOC emission reductions (with the desired change in NOx emissions) and (2) be less costly and more cost-effective than property-based standards or performance-based standards developed for other circumstances (e.g., Federal RFG and California RFG standards).

APPENDIX A

SCOPE OF WORK

TASK ASSIGNMENT PROPOSAL
SCOPE OF WORK

APPENDIX B

INTRODUCTION TO ARMS

APPENDIX B: INTRODUCTION TO ARMS

B.1 Introduction

The Advanced Refinery Modeling System (**ARMS**) is a high-performance, desktop linear programming (LP) modeling system designed specifically for analyzing the technical and economic performance of (1) the refining sector of the U.S. and other countries, disaggregated by region, refinery type, or other sub-division, and (2) individual refineries.

It is designed to support policy analysis and business planning studies dealing with the technical and economic response of the refining industry (or individual refineries) to real or prospective changes in public policy, regulation, and/or market conditions. Consistent with this purpose, ARMS represents refinery processing operations and economics in **engineering** terms, for specific scenarios describing the sector's capital stock, market situation, and regulatory environment.

ARMS is an advanced system embodying established and proven modeling technology. The developers of ARMS (David S. Hirshfeld and Jeffrey A. Kolb) formerly operated the refining economics practice of Sobotka & Company, Inc. (SCI). At SCI, they developed an earlier refinery modeling system (called the Desktop Refining Model) and applied it in numerous extended and quick-response analyses of the effects of environmental regulation on the U.S. refining sector. Many of these studies were performed for the U.S. Environmental Protection Agency (EPA), in connection with the implementation of the federal oxygenated and reformulated gasoline programs.

The LP model in ARMS comprises (1) a symbolic, computer-readable **model statement**, specifying the model's mathematics and logic and (2) an explicit, computer-readable **model database**, containing sets of numerical input values in tabular and relational form. Each distinct pairing of a model statement and a set of input values leads to a distinct model instance, or **case**, that ARMS processes and solves. Typical analyses of policy and planning issues involve creating and processing hundreds of cases.

In its latest version (as of the date of this proposal), a typical instance of ARMS comprises approximately

? 725 constraints (equations and inequalities)
? 2,400 activities (variables)
? 29,500 non-zero coefficients

ARMS is a collection of custom-designed computer programs for creating, modifying, and managing model statements, databases, and cases. The programs form an open, flexible, and easy-to-enhance system, because they are implemented by means of a fourth-generation optimization modeling toolkit (**MathPro**^{R}) and an advanced model solver (**XPRESS-MP**^{R}). By virtue of its advanced design and implementation, ARMS supports quick response analyses, even when the analysis calls for modifying or extending the model statement and for running many scenarios in a short time.

B.2 Overview Of ARMS

B.2.1 Basic concepts

ARMS is a *static*, *process-oriented*, *disaggregated*, *linear programming (LP)* representation of the operations and economics of specified elements of the refining sector, including individual refineries, and closely related petrochemical facilities.

? *Linear programming*: ARMS is an *optimization* model, whose solutions define optimal refining operations and economics for the specified refinery or refining aggregate and policy scenario.

? *Disaggregated*: ARMS represents refining facilities (that is, capital stock within refinery battery limits) at a user-specified level of disaggregation: an individual PADD or a group of PADDs (e.g., PADDs 1-4), an individual DOE region or a group of such regions, a group of similar refineries in a region or refining center (e.g., complex refineries on the U.S. Gulf Coast), or an individual refinery.

? *Process-oriented*: ARMS represents refining operations, process by process, in technoeconomic or engineering (not econometric) terms.

? *Static*: ARMS represents an average day's operations of the specified refining aggregate or refinery in the specified time period (year and season), with no inter-temporal flows such as inventory build-up or draw-down.

The solution to an ARMS case defines a pattern of refining operations for the region of interest and a set of prices for feeds, products, and refinery process capacity that minimize aggregate refining cost or maximize aggregate profit contribution, for a given set of boundary conditions (including regulatory requirements, usually expressed in terms of product specifications).

In this context, *profit contribution* is the difference

Product Revenues - Costs of (Crude + Other Feeds + Purchased Energy + Catalysts/Chemicals) - Investment Amortization

where the revenues and all of the cost items are per barrel of throughput, with fixed costs not considered.

ARMS is a partial equilibrium model. That is, the solution to an ARMS case simulates the operation of the refining sector such that

- ? the market for each product clears at the computed prices;
- ? each refinery is in competition with all others in the given region; and
- ? all competitors have full information about the market.

Solutions to sequences of ARMS cases can trace out refinery supply functions and indicate the impacts on refining operations and economics of prospective changes in energy and environmental policy and regulation; crude oil and feedstock quality, price, and availability; product demand and specifications; and refining capital stock.

B.2 Areas of Application

ARMS has been applied to support analyses of a wide range of issues affecting the refining sector, including:

- ? Economic impacts on the refining sector - and resulting costs to consumers - of the requirements to produce "green" fuels -- such the oxygenated and reformulated gasolines mandated by the fuels provisions of the Clean Air Act Amendments of 1990 (CAAA) -- in the U.S. and other countries
- ? Economic impacts on the refining sector, and the attendant capital requirements, of available and prospective new process technologies, including those for producing green fuels
- ? Technical and economic impacts on the refining sector of individual provisions of the CAAA, such as the "opt-in" provision and the "anti-dumping" requirements of the reformulated gasoline program
- ? Differential technical and economic impacts on the refining sector of different regulatory regimes for reformulated gasolines and other green fuels
  - -- Reformulated gasolines: EPA Simple Model for certification vs. EPA Complex Model for certification vs. CARB Phase 2 standards
  - -- Diesel fuel: EPA regulations vs. CARB Phase 2 regulations on sulfur level and aromatics content
- ? Technical requirements and incremental costs for phasing lead out of gasoline, in various countries

- ? The costs of generating emissions credits in the refining sector by producing gasolines whose emissions performance exceeds regulatory requirements.

- ? Technical and economic impacts on selected portions of the petrochemicals sector of oxygenated and reformulated gasoline production in the refining sector

- ? Effects of environmental regulations on the volume and quality requirements of U.S. crude oil demand and oil imports (crude oil, blendstocks (including oxygenates), and refined products)

- ? Effects on U.S. oil imports (crude oil, blendstocks (including oxygenates), and products) and overall refining economics of prospective octane-enhancing additives (e.g., MMT) for gasoline blending

- ? Impacts of the trend to a heavier and more sour crude slate on (1) the requirements for capital investment in the refining sector; (2) the investment and operating costs associated with meeting environmental regulations; and (3) the continuing rationalization of the U.S. refining industry.

- ? The relative values of various crude oils, by region and by refinery type.

- ? The relative values of gasoline blendstocks and other refinery inputs under different regulatory standards and market conditions, by region, refinery type, and season.

Continuing extension of ARMS is expanding its realm of applications even further.

B.3 Special Features

ARMS is "data-driven" and easily enhanced. Data-driven operation enables one to change data values and create scenarios without changing the mathematics or any computer programs. It is the result of strict separation of the model's mathematics and data within ARMS, an advanced design feature. ARMS's design and implementation facilitate a continuing stream of enhancements to the model's structure, without conventional computer programming and its attendant costs in dollars and time.

ARMS contains representations of many existing and prospective new refining processes and process options, some geared to producing oxygenates, oxygenated and reformulated gasolines, and low-sulfur gasolines and diesel fuels; others to improving refining economics in general. The continuing effort to capture new refining technology in ARMS gives the system an unmatched capability to (1) analyze the effects of technological advances on the costs of environmental regulations and other policies bearing on the refining sector and (2) simulate refiners' technological response to new environmental regulation and changes in market conditions.

ARMS contains detailed representations of the most recent regulations pertaining to transportation fuels. In particular, ARMS represents the production of (1) federal **oxygenated** and **reformulated** gasolines consistent with the federal Clean Air Act Amendments (under EPA's "simple" model or "complex" model for gasoline certification) and (2) **reformulated** gasolines consistent with the California Air Resources Board's Phase 2 regulations. Similarly, ARMS represents the production of diesel fuels to both the new federal and the new California specifications.

Because fluid catalytic cracking (FCC) operations are the most important single determinant of refining economics in conversion refineries and because FCC units have exceptional flexibility, ARMS contains an especially detailed representation of FCC operations. The representation covers numerous feedstocks (ranging from distillates to residual oils), catalyst types, operating modes, and conversion levels.

Because the prospective marginal cost (price) of blended products is usually a key result of ARMS-based analyses, ARMS's finished product blending section receives special attention. ARMS includes a detailed representation of finished product blending to specification. The specifications represented in ARMS include industry standards, requirements imposed by the Clean Air Act Amendments -- including all gasoline properties registered in the Complex Model, driveability index, and other regulatory requirements.

B.4 Data Content

At present, the ARMS database comprises more than **100** tables of input data values that give numerical expression to the refining representation in ARMS. The database includes representations of about **150** different foreign and domestic crude oils, **48** refining and related petrochemical processes, and **35** refined products - including three grades each of conventional, oxygenated, and reformulated gasoline.

In general, data elements in the ARMS database are in two categories: boundary conditions and technoeconomic values. The two categories have the same computer-readable (relational) format, but play different roles in analyses.

? *Boundary conditions* express assumptions about certain future conditions that refining operations must satisfy, such as regulations, crude oil availabilities, product demands, product specifications, and crude and product prices.

- ? *Technoeconomic values* characterize the performance of refining operations in a given region and time period, in terms of assays for each crude represented, input/output coefficients for each refining process represented, and blending properties for each blendstock represented.

Changes to the boundary conditions express changes in assumptions about future conditions, and such assumptions underlie each scenario and ARMS case. Changes in the technoeconomic values usually express refinery-specific process data or significant and enduring changes in

refining technology. A specified set of boundary conditions and technoeconomic values express a scenario for analysis and establish the corresponding ARMS cases.

Using ARMS in a given analysis involves changing elements of the boundary conditions from case to case while (in general) holding the technoeconomic values constant.

Permanent changes in technoeconomic values in the ARMS database usually result from targeted efforts to enhance ARMS, and the technoeconomic values usually remain invariant in a given analysis.

B.5 Boundary Conditions

For the region and time period of interest, the model's **boundary conditions** (scenario-specific **inputs**) include:

- ? Prices and availabilities (maximum and minimum) of crude oils
- ? Prices and availabilities of purchased feedstocks (including oxygenated blendstocks) and additives
- ? Prices and availabilities of purchased utilities
- ? Prices and demands for finished products
- ? Aggregate processing capacities available (nameplate capacities and stream factors, by process)
- ? Specifications (e.g., octane, RVP, T_{90}, etc.) for the most important blended products, including all gasolines, jet fuels, diesel fuel, heating oil, and residual fuel
- ? Emissions reduction targets for gasolines subject to performance-based regulations
- ? Recipes for those products not blended to specification in the model
- ? Capital investment cost (in $ per throughput barrel) for additions to capacity, by process
- ? Limits (if applicable) on aggregate additions to capacity, by process

Each set of boundary conditions listed above is defined in one or more discrete tables in the ARMS database.

B.6 Key Outputs

Solutions to a given ARMS case (scenario-specific **outputs**) define optimal operations in the refining aggregate of interest, in terms of:

? Volumes consumed and marginal value of crude oils, purchased blendstocks, and additives
? Compositions and qualities of finished products blended to specification
? Aggregate capacity utilization and the marginal value of new capacity, by process
? Aggregate investment in new capacity
? Volumes produced and marginal cost of each finished product
? Marginal cost of each intermediate refinery stream and blendstock
? Marginal cost of satisfying each individual specification, by blended prooduct

All of these outputs reside in the ARMS database, and may be viewed interactively, compared side-by-side, and printed under user control.

B.7 Key Assumptions

Every LP model, indeed every mathematical model of any kind, rests upon various assumptions, some specific to the model at hand and others associated with the modeling technique employed.

ARMS rests on assumptions of both kinds. The two most significant ones -- having to do with linearity and aggregation -- are characteristic of LP models of refining operations, and not unique to ARMS.

B.7.1 Linearity

As its name suggests, linear programming deals with models whose constraints and relationships between variables are linear. If the system being modeled contains essential nonlinearities, the LP model builder must approximate them with special relationships in linear form (sometimes combined with advanced procedures for solving the model).

Many aspects of refining operations represented in ARMS are truly linear (e.g., material balances, energy balances, and some product blending operations); but others are not (e.g., process operations, quality pooling, some elements of product blending, the Complex Model, etc.). Hence, ARMS contains a number of linear approximations of nonlinear phenomena.

Capturing explicitly the nonlinear responses of refining processes, quality pooling, and product blending is important in an LP model intended for short-term operations planning and scheduling in a specific (real) refinery. In that realm of application, accurate representation of specific responses to specific changes in feedstocks and process variables is essential, because model outputs guide short-term operating decisions. But capturing these responses in detail is not appropriate for policy analysis and business planning, where one is concerned with refinery-specific or industry-wide economic and technical responses to prospective changes in operating environment, in future time periods, and with capital stock that in part may not yet exist.

B.7.2 Aggregation and Over-Optimization

Some ARMS applications appear at first glance to warrant modeling operations at each individual refinery in a specified region. Modeling at that level of disaggregation is neither feasible (with current computing capabilities and analytical techniques -- and client resources) nor appropriate for planning and policy analysis. So, for applications involving regional or sectoral analysis, ARMS represents refining operations in the aggregate for the specified region or regions.

In such instances, each ARMS case represents average daily operations in a specified regional aggregate of refining capacity (as discussed in Section 2.1 of this Appendix). In particular, ARMS represents the regional aggregate as a single "notional" refinery, denoting the region's refining capacity, process by process. For the specified region and time period, ARMS's notional refinery (1) accepts a crude slate that encompasses all of the crude oils forecast to be available, and (2) produces a product slate in volumes forecast to be required in the specified region and time period.

One can think of the notional refinery as representing totally coordinated operation of the individual refineries in the specified region. In this idealized realm, refineries trade intermediate refinery streams and blendstocks freely among themselves so as to make optimal use of all refining capacity in the region, process by process, regardless of the refinery(s) in which the processing capacity resides. Considerable trading of this kind actually occurs in the refining sector; but in volumes limited by physical and institutional barriers and by the capabilities of the capital stock in place.

Because a regional aggregate representation implies inter-refinery trading beyond what can actually occur, ARMS solutions in such analyses tend to indicate higher aggregate profit contributions and/or lower product prices than would occur in practice for a given set of boundary conditions. The technical term for this modeling phenomenon is "over-optimization". Over-optimization is a general characteristic of all model-based analysis of the refining sector, whenever such analysis involves modeling aggregate refining capacity (as opposed to disaggregating to the individual refinery/process level).

B.7.3 Assessment of Key Assumptions

In practice, the linearity and aggregation assumptions seldom if ever impair the utility of ARMS analyses in policy and planning studies. Most analyses focus on the *differences* in solutions between ARMS cases and not on the specifics of the solution to any one case. Moreover, an analyst familiar with ARMS and with actual refining operations can neutralize most of the effects of linearization and the tendency to over-optimize, by calibrating the model to a reference time period. Calibration involves adjusting boundary conditions and technoeconomic values until ARMS yields solutions reflecting actual market prices and volumes for refined products in the reference period. Virtually all studies involving ARMS begin with a set of calibration runs.

Experience has shown that ARMS represents the flexibility and limits inherent in refining and product blending operations quite well -- well enough to generate useful information and insights on the industry's overall and marginal economics.

APPENDIX C

COMPARISON OF
THE COMPLEX MODEL AND THE PREDICTIVE MODEL

APPENDIX C: COMPARISON OF THE COMPLEX MODEL AND THE PREDICTIVE MODEL

The discussion in Chapter 5 concerning the projection of fuel emission impacts from late model vehicles mentions that two models exist which can perform such projections: the EPA Complex Model and the Tech 4 portion of the CARB Predictive Model. This appendix reviews the various emission projections contained in these two models and performs some limited evaluations of these projections against actual emission data.

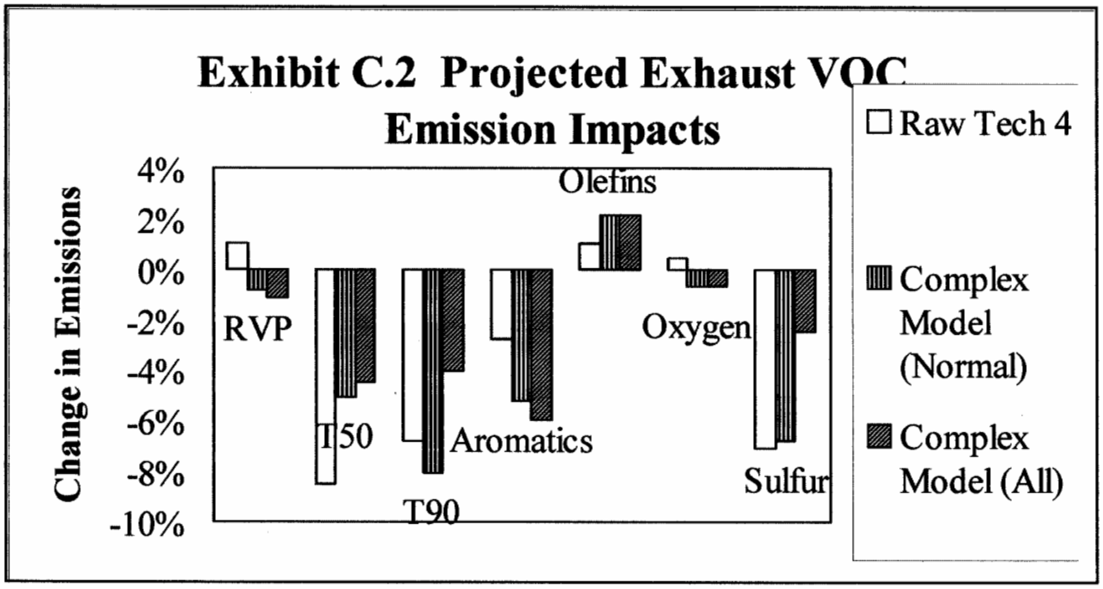
C.1Effect of Fuel Quality on Exhaust VOC and NOx Emissions

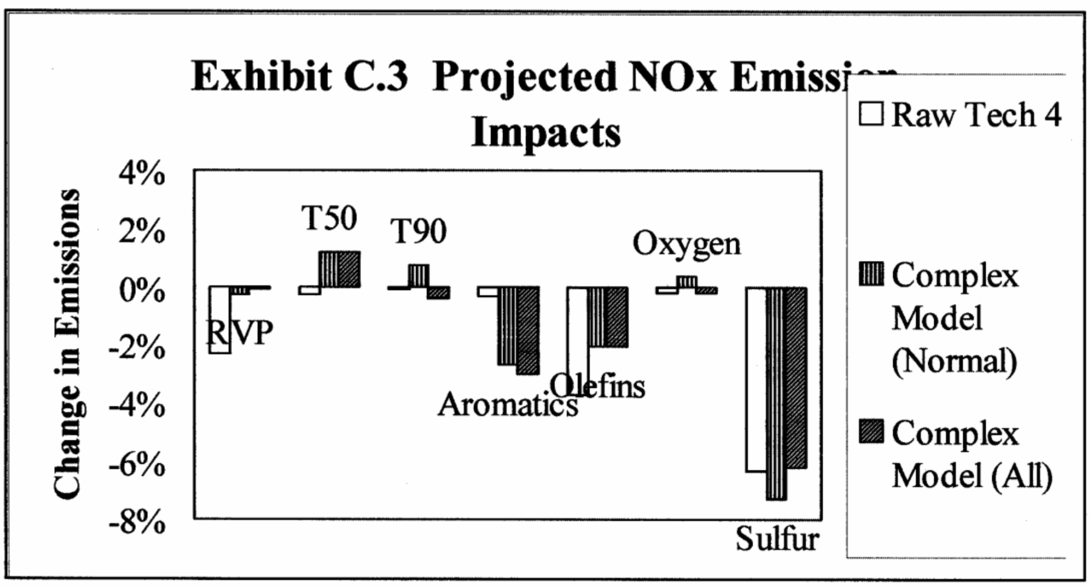
A brief comparison of the emission projections contained in the two models is performed in this section. Starting with Phoenix baseline gasoline, as estimated in Chapter 6, individual fuel parameters were perturbed and their emission impacts determined using the two models. The levels of each perturbed fuel parameter were set to approximate the greatest degree of change occurring with any of the fuel options being evaluated in this study. For example, fuel sulfur was reduced to 30 ppm, as this is the level seen in California RFG-II. **Exhibit C.1** shows baseline Phoenix gasoline and the various fuel perturbations.

Exhibit C.1: Table Fuels Used to Compare Fuel Effects in Predictive and Complex Models

	Phoenix Base	RVP	T50	T90	Aromatics	Olefins	Oxygen	Sulfur
MTBE (wt% O_2)	0.1	0.1	0.1	0.1	0.1	0.1	2.1	0.1
ETBE (wt% O_2)	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethanol (wt% O_2)	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAME (wt% O_2)	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SULFUR (ppm)	164.2	164.2	164.2	164.2	164.2	164.2	164.2	30.0
RVP (psi)	6.7	6.4	6.7	6.7	6.7	6.7	6.7	6.7
E200 (%)	42	42.0	54.8	42.0	42.0	42.0	42.0	42.0
E300 (%)	82.9	82.9	82.9	91.7	82.9	82.9	82.9	82.9
Aromatics (vol%)	35.3	35.3	35.3	35.3	20.0	35.3	35.3	35.3
OLEFINS (vol%)	11.3	11.3	11.3	11.3	11.3	4.0	11.3	11.3
BENZENE (vol%)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3

The results of using the Complex Model and the raw version of the Tech 4 Predictive Model are shown in **Exhibits C.2 and C.3** for exhaust VOC and NOx emissions, respectively. For comparison, the Complex Model projections for both normal emitters and combined normal/high emitters are shown. The Tech 4 model does not distinguish between the two types of vehicles. The Tech 4 model was developed from a database containing both types of vehicles, though the great majority of the data were from normal emitters.





As can be seen, from Exhibit C.2, both models project the same directional emission effects for the various fuel modifications. The two exceptions are RVP and oxygen. The emission effects in these two cases are small, partly because the change in RVP is limited by an absolute lower limit of 6.4 RVP per EPA regulations and the fact that both models project that oxygen alone (aside from other fuel changes accompanying the addition of oxygenates) has little effect on these late model vehicles. The Tech 4 model projects a much larger impact of reduced T50 on exhaust VOC emissions than that of the Complex Model for either normal or high emitters. The opposite is true for reduced aromatic content and olefins. The Tech 4 model projects the same effect of fuel sulfur as the Complex Model for normal emitters, but the overall impact of the Complex Model is less than half the effect. This is due to the fact that the Complex Model attributes 55% of in-use exhaust VOC emissions to high emitters and the fact that it projects that reduced sulfur levels increase exhaust VOC emissions from these vehicles slightly.

Regarding NOx emissions, Exhibit C.3 shows some similarities and some distinct differences. Both models project the same directional impacts for the reduction of RVP, aromatics, olefins and sulfur. While the two models' projections are nearly identical for sulfur, the others differ in magnitude significantly. The Tech 4 model projects much larger impacts for reduced RVP and olefins, and a much smaller impact for reduced aromatics. The Tech 4 model and the overall Complex Model agree on the effect of reduced T90. Within the Complex Model, reduced T90 increases NOx emissions from normal emitters and decreases NOx emissions from high emitters. Again, the two models differ on the impact of oxygen. However, again the overall impact of adding oxygen is projected to be small. The two models disagree in both direction and magnitude on the impact of reduced T50 on NOx emissions, with the Tech 4 model projecting a slight decrease and the Complex Model projecting a 1% increase. It should be noted that except for the impact of sulfur, all of the emission impacts shown in **Exhibit C.3** are less than 4% and are thus, relatively small.

Overall, while the two models agree in some areas, there are more differences than agreements. Both models were generated from essentially the same emission database using similar statistical techniques. Thus, their different projections should be an indication that significant uncertainty still exists regarding the effect of fuel quality on exhaust emissions. The projections of both models should be viewed in this light. The next two sections will examine two fuel parameters, RVP and T50, and their impact on exhaust VOC emissions.

C.2 Effect of RVP on Exhaust VOC Emissions

Based on the AAMA fuel survey, the RVP of 1995 Maricopa County gasoline is among the lowest in the nation, with gasoline averaging 6.7 RVP. This RVP level is at the extreme of the fuel properties in the databases used to develop both the Complex and Predictive Models.

Statistical models, such as these two models, tend to perform more poorly at the extremes of their underlying data than they do closer to the mid-points of the data. For example, only 14 of the over 400 fuels tested in the Complex Model database were at or below 7.5 RVP. Less than 10 had an RVP below 7 psi.

Reducing RVP even further will reduce non-exhaust VOC emissions. However, as shown above in Exhibit C.2, the Complex and Tech 4 Models project opposite effects for exhaust VOC emissions. While the degree of RVP reduction is limited to due to EPA regulations (it is not lawful to sell gasoline with an RVP below 6.4), the potential change in exhaust VOC is significant relative to the non-exhaust VOC benefit projected by MOBILE5a. It would be helpful to better understand which model may be correct (i.e., are exhaust VOC increasing or decreasing with further reductions in RVP).

A number of test programs have evaluated the impact of reduced RVP on exhaust emissions. The most carefully controlled studies, such as those performed by Auto-Oil, EPA (in its RFG testing, but not in its Emission Factor testing), API, and General Motors-California Air Resources Board-Western States Petroleum Association (GM-CARB-WSPA), reduced RVP while holding as many other fuel parameters constant as possible. In particular, the low RVP test fuels usually had modest or no increases reductions in T50. While this is acceptable in a scientific study aimed at separating the impact of various fuel parameters, it does not address the impact of higher T50 levels on emissions. It also makes it more difficult to identify any combined effects of RVP and E200 or E300 which may differ from the sum of their independent effects.

Exhibit C.4 summarizes the results of the above four gasoline test programs regarding the impact of reduced RVP on exhaust non-methane hydrocarbon (NMHC, which very similarly approximates VOC) emissions.

Exhibit C.4: Effect of RVP on Exhaust NMHC Emissions				
Test Program	Initial RVP (psi)	Final RVP (psi)	Oxygenate	Change in Exhaust NMHC per 1.0 RVP Decrease (%)
Normal Emitters				
EPA RFG I [4]	8.3	7.6	MTBE	-3.9%
EPA RFG II [5]	7.6	6.4	MTBE	-0.7%
EPA RFG III [6]	7	6	ETBE	+2.3%
EPA RFG III	6.8	6.2	ETBE	+4.0%
Auto-Oil RVP-Oxygenate [7]	8.7	7.8	None	-4.9%
	8.8	8.0	None	-1.7%
	9.6	9.0	Ethanol	-8.5%
	9.6	9.3	Ethanol	-16.1%
	8.8	8	MTBE	-2.7%
API Oxy-RVP [7]	10.4	8.9	None	-9.8%
	8.9	7.8	None	-13.3%
	7.8	7	None	+9.1%
GM-CARB-WSPA [7]	7.8	6.7	MTBE	-3.3%
	7.7	6.8	MTBE	-9.2%
EPA Complex Model	--	--	All	-2.9%
High Emitters				
EPA RFG I	8.3	7.6	MTBE	2.1%
EPA RFG II	7.6	6.4	MTBE	-2.3%
EPA RFG III	7	6	ETBE	-6.5%
EPA RFG III	6.8	6.2	ETBE	2.1%
EPA Complex Model	--	--	All	-4.2%

The vehicle emission data from the programs shown in Exhibit C.4 have been segregated according to the base emissions of the vehicle, according to the methodology used by EPA in developing the Complex Model.[1] Normal emitting vehicles have base NMHC emissions below 0.8 g/mi NMHC, which also matches the definition of a normal emitter in EPA's MOBILE5 model. High emitters have

[1] This was not done for the T50 emission analysis, as the EPA test programs were the only programs to test high emitters and EPA did not evaluate the impact of T50 on emissions to the extent achieved by Auto-Oil.

base emissions above this level and generally have some engine or emission control system problem present.

The normal emitter data show a definite trend of higher benefits at high base RVP and lower benefits or even dis-benefits at base RVPs below 7.6 psi. In fact, the EPA and API testing show that reducing RVP below 7.0 and 7.6 psi, respectively, increases exhaust NMHC emissions. This is shown more clearly in **Exhibit C.5**, where the exhaust NMHC emission effect is plotted against the base RVP. A linear least-squares regression was performed which weighted each data point by the number of vehicles included in that particular test program. The trend indicates that RVP reductions produce a greater benefit at high base RVP levels and a lower benefit or even a dis-benefit at very low RVP levels. The r^2 of the regression was slightly more than 0.4. The r^2 of the regression was roughly 0.15 without the weighting by vehicle number, indicating that the test programs which included the most vehicles produced the most consistent results, as would be expected.[2]

High emitting vehicles tend to have more variable emissions even when tested on the same fuel repeatedly. This leads to highly variable measured fuel effects in general. The high emitter data in Table 1 are in fact more variable than the normal emitter data, with both increases and decreases at moderate and low base RVP levels. Despite this variability, the statistical analysis used to develop the Complex Model found the RVP effect on exhaust VOC emissions for high emitters differed statistically from that for normal emitters. The result was a projection of a larger 4.2% reduction in exhaust VOC per decrease of 1.0 RVP.

The trend shown in Exhibit C.5 should only be used as a general indication of the effect of RVP reductions on exhaust VOC emissions. While RVP was the primary fuel parameter being modified in these studies, changes in other fuel parameters did occur and could be affecting the results. To account for these other fuel parameter variations, the Complex and Predictive Models were both used to project the emission impacts of the fuels listed in **Exhibit C.5**. The weighting of the technology groups in the Complex Model was adjusted to match those in each test program. The raw version of the Tech4 portion of the Predictive Model was used, while the normal emitter portion of the Complex Model was used. The differences between these projections and the actual data are summarized in **Exhibit C.6**.

[2] One of the fuel pairs described in Exhibit C.4 only reflected an RVP decrease of 0.3 psi (one of the two ethanol-containing fuels in the Auto-Oil study) . This is quite low relative to the accuracy of RVP measurements. However, the emission effect found for this pair of fuels was closer to the trendline than that for the ethanol fuel pair which reflected a 0.6 RVP reduction. Thus, inclusion of the first pair does not appear to be inappropriately affecting the results.

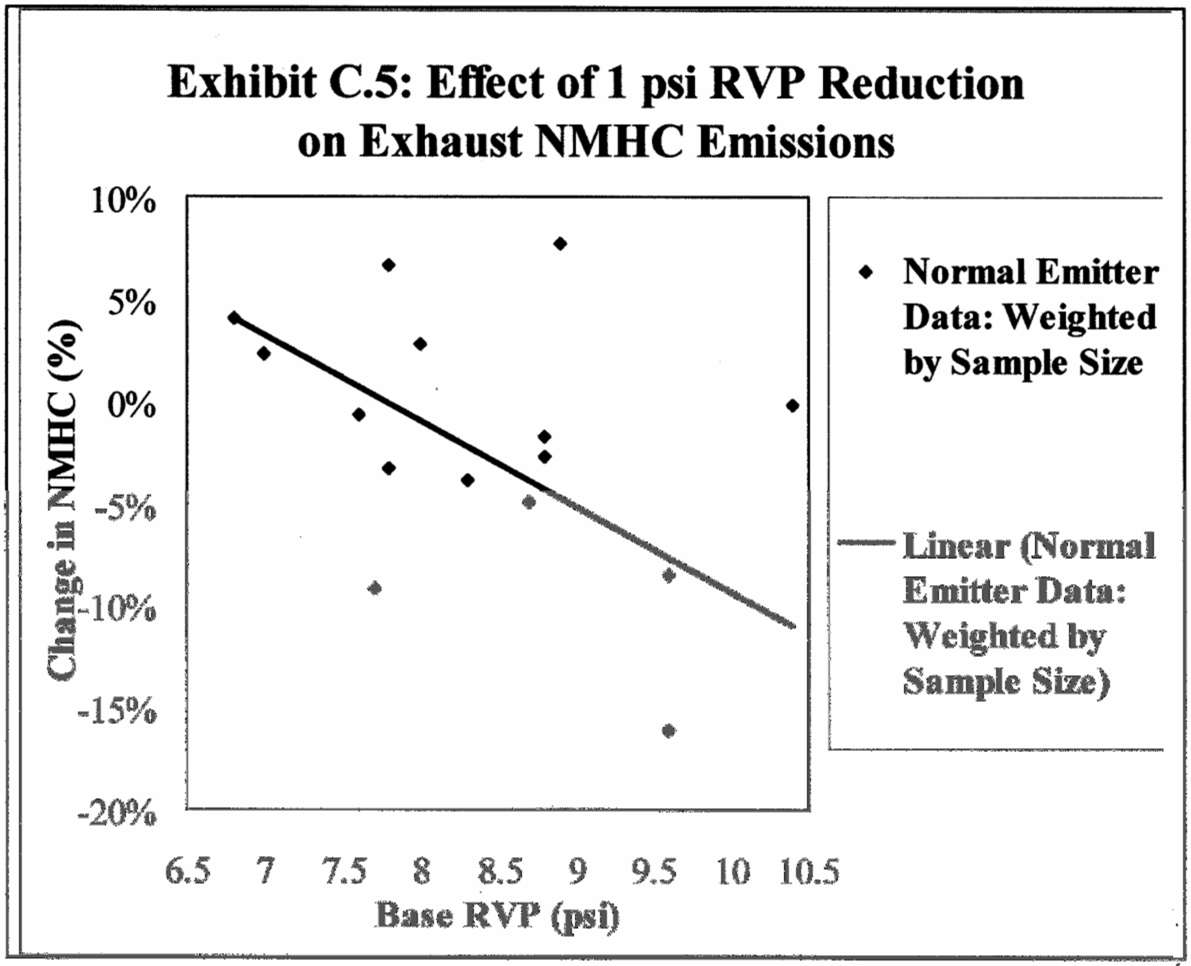


Exhibit C.5: Effect of 1 psi RVP Reduction on Exhaust NMHC Emissions
10%
5%
0%
-5%
-10%
-15%
-20%
Change in NMHC (%)
6.5
7
7.5
8
8.5
9
9.5
10
10.5
Base RVP (psi)
Normal Emitter Data: Weighted by Sample Size
Linear (Normal Emitter Data: Weighted by Sample Size)

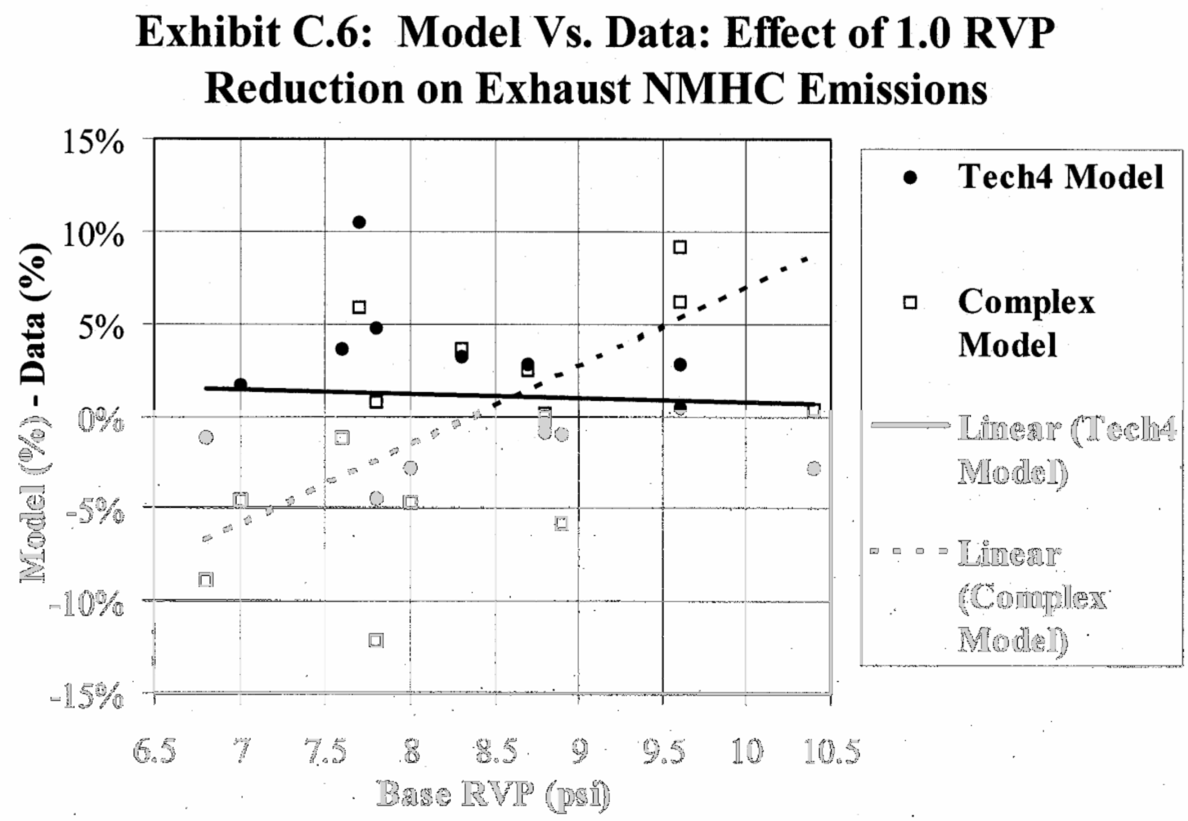


Exhibit C.6 indicates that the Complex Model over-estimates the emission benefit of reducing RVP at low base RVP levels, while under-estimating the benefit at high base RVP levels. The errors associated with the Predictive Model are lower on average and do not vary with base RVP level. In particular, the Tech 4 model is able to predict the diminishing benefit of RVP reductions as the base RVP decreases. In this particular situation (i.e., where RVP is being reduced with minimal impact on other fuel parameters), it appears that the Tech 4 Predictive Model is more likely to produce an unbiased estimate of the impact of reduced RVP levels than the Complex Model.

C.3Effect of T50 on Exhaust VOC Emissions

T50 is an important parameter in this analysis because current Phoenix fuels have higher than average T50 levels and because the two models project different benefits for reducing T50 levels. As shown in Exhibit C.2, the Tech 4 model projects nearly twice the benefit of reducing T50

from 216°F to 190°F as the Complex Model. However, the differences between the two models increases as the base T50 increases. According to the 1995 AAMA fuel survey, the T50 levels in Maricopa County were 226°F for regular gasoline and 238°F for premium gasoline. These levels are significantly above the average of 216°F being projected for 1996 Phoenix gasoline with no regulatory change. It is important to note what the effect of reducing T50 temperatures would be if baseline T50 levels were
higher (nearer those in the 1995 AAMA survey).

Both the raw Tech 4 Model and the Complex Model were used to model the Phoenix base fuel shown in Exhibit C.1 with an increased T50 temperature of 228°F (a weighted average of the regular and premium T50 temperatures). Reducing T50 from 228oF to 190oF reduced exhaust VOC emissions by 8% (Complex Model) to 15% (Tech 4 Model). The reduction from 216oF to 190oF modelled earlier reduced exhaust VOC emissions by 5% (Complex Model) to 8% (Tech 4 Model). Thus, an increase in the base T50 temperature of only 12°F increased the emission impact according to the two models by a factor of 1.6-2.0. Two conclusions can be drawn from this: 1) the base T50 temperature of Phoenix gasoline is an important parameter, and 2) the two models used to predict the exhaust VOC emission impact agree on direction, but differ in magnitude by almost a factor of two.

A number of test programs have tested fuels with varying levels of T50 and T90 (or E200 and E300). However, the most thorough studies in terms of the number and variety of fuels evaluated are those performed by Auto-Oil. Three Auto-Oil studies have evaluated changes in T50 and T90. One is the initial Auto-Oil fuel-emission study, which investigated the impact of aromatics, MTBE, olefins and T90 on emissions, and is commonly referred to as the AMOT study. T50 was not varied in a controlled manner and generally correlated with MTBE and T_{90}. Thus, this study provides a good indication of the combined effect of T50 and T90, but not of T50 and T90 individually.

The second program is generally referred to as the Heavy-Hydrocarbon (HC) study. This study focused on the emissions impact of various refinery sources of the heavier components of gasoline, such as reformate and alkylate. Again, T50 and T90 tended to vary together. However, the specific levels of T50 associated with various T90 levels and vice versa differed from those included in the AMOT study. Thus, some indication of the relative influence of the two parameters can be drawn from the data. While the aromatics content also changed in this study, there were high and low aromatic levels for each combination of T50 and T90. Thus, changes in aromatics should not bias the evaluation of the impact of distillation properties on emissions.

The third phase focused specifically on independent changes in T50 and T90. It also included two fuels (C7 and C8) which had exactly the same RVP, T50, and T90 levels as two other fuels (C4 and C6), but had higher sulfur levels than the rest of the fuels tested in this study. Their inclusion would not have added any new information regarding the effect of T50 on emissions and would have added a confounding effect due to the changing sulfur level. Thus, these two fuels were excluded in this analysis. This study is referred to here as the T50-T90 study.

Two separate analyses were performed to compare the predictions of the Tech 4 and Complex Models and the measured data from these three studies. The need for two sets of analyses arises from the fact that the vehicles tested by Auto-Oil do not reflect the in-use emissions weighting of the 9 technology groups. In the first set of analyses, the data are combined according to the emission weighting of the technology groups and compared to the standard model predictions. In the second set of analyses, the measured emission data are compared to a reweighted Complex Model prediction. Since the Tech 4 model does not differentiate between technology groups, its predictions are the same in both cases, though the measured emission impacts differ in the two cases.

Exhibits C.7 through C.12 depict the results of the first set of analyses. Measured exhaust NMHC emissions versus T50 from the Auto-Oil AMOT, Heavy-HC and T50-T90 studies have been combined to represent the technology group weights implicit in the Complex Model. First, the emission data for all vehicles within a technology group were normalized to that of the average vehicle on the Clean Air Act baseline gasoline and then averaged to produce a single technology group emission level for each test fuel. The technology group averages were then weighted using the Complex Model weighting factors. This procedure mimics that used to develop the Complex Model from the models for each technology group. Also shown in these three figures are the projections of the Raw Tech 4 model and the normal emitter portion of the Complex Model. These projections are represented by best-fit quadratic equations normalized to the emissions from a single test fuel from each study (L, 17A, and C2 from the AMOT, Heavy-HC, and T50-T90 studies, respectively).

Exhibit C.7 indicates that exhaust VOC emissions tend to increase with increasing levels of T50, though other fuel factors clearly have an influence. This is not unexpected, since this study evaluated the effect of large changes in aromatics, olefins and MTBE contents, as well as distillation properties. Also, as mentioned above, T50 and T90 levels were correlated to some degree. Thus, the upward trend in exhaust VOC emissions is a function of both increasing T50 and T90 temperatures. As can be seen, the projections of both models are very similar and both fit the data reasonably well.

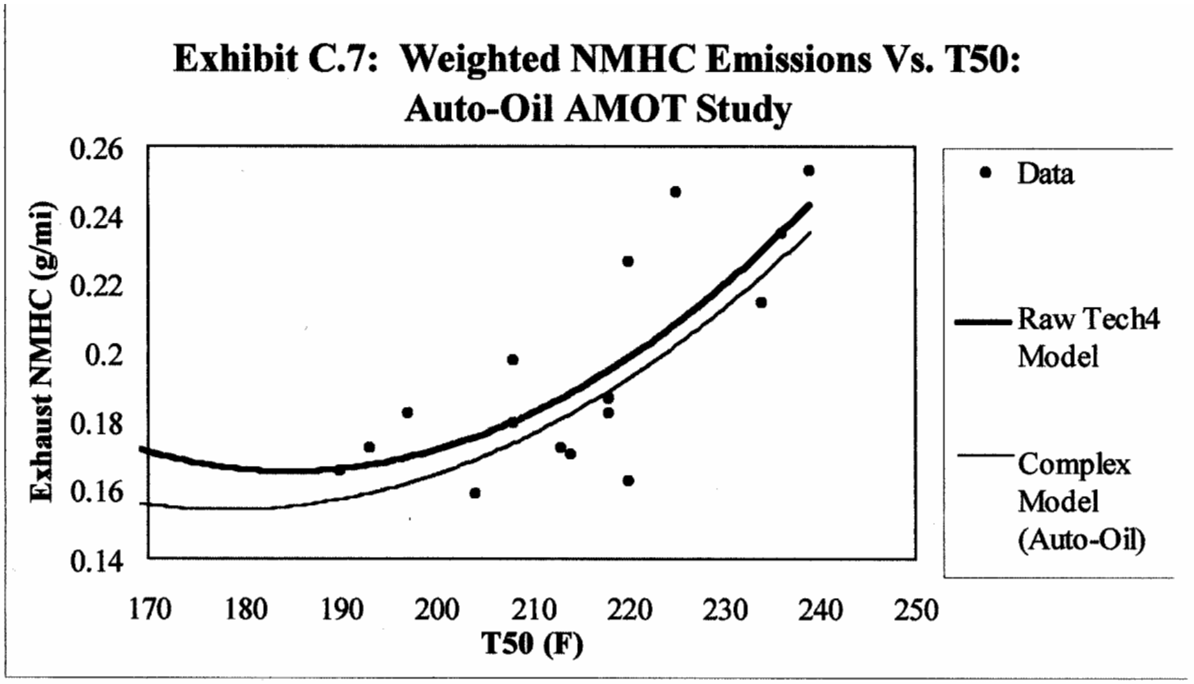


Exhibit C.8, showing the Heavy-HC study data, shows a more consistent trend in emissions with T50 than the AMOT study. This is due to the fact that fewer non-distillation parameters were varied in this studies. In the Heavy-HC study, T50 was again correlated with T90. Again, the projections of both models are very similar and both fit the data reasonably well.

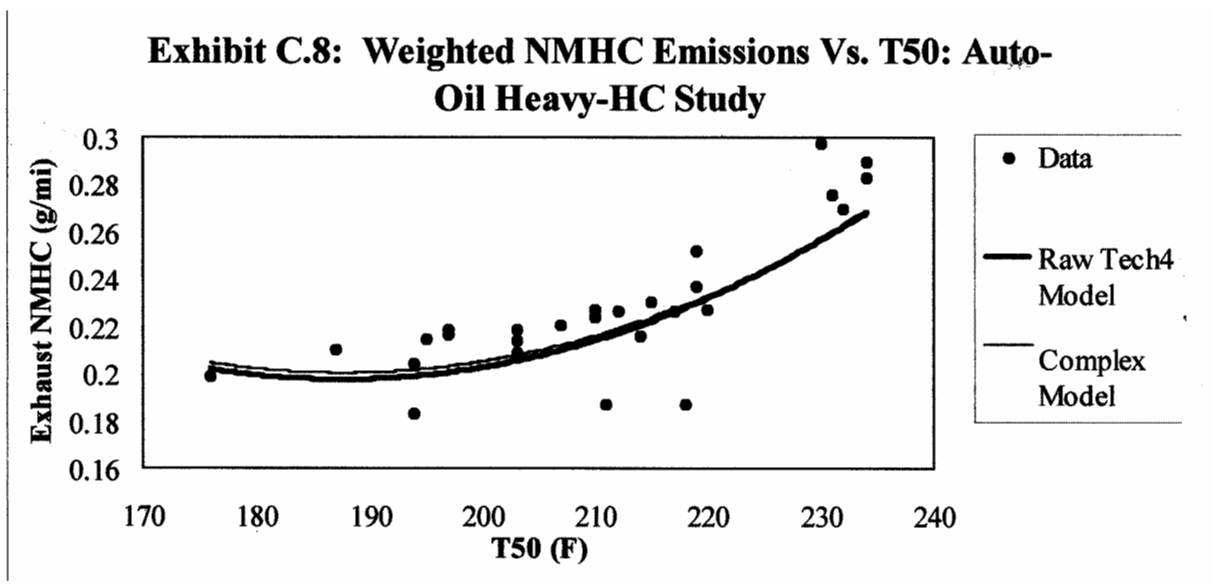
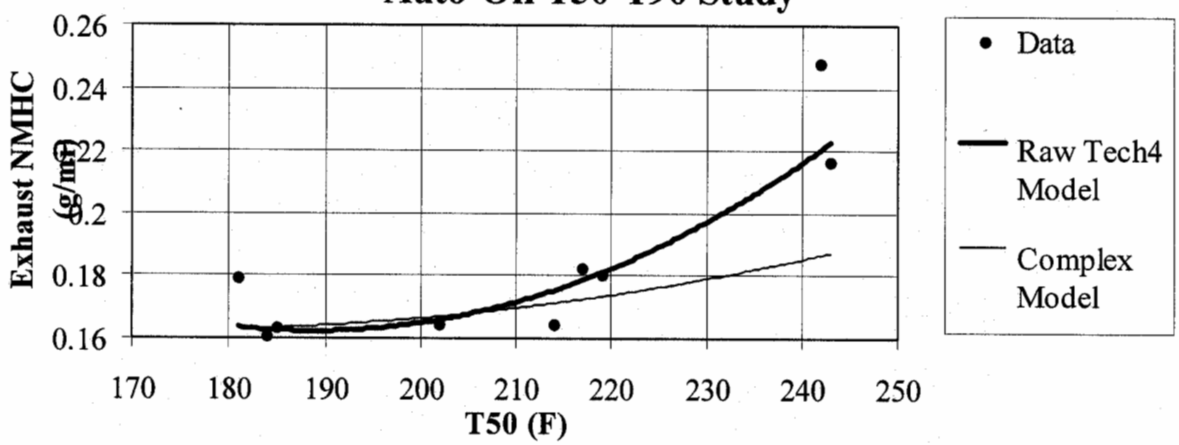


Exhibit C.9, showing the T50-T90 study data, again shows a fairly consistent trend in emissions with T50. This study included fewer fuels than either of the previous studies. However, the distillation properties of the high T50 fuel with the highest emissions is very similar to 1995 premium gasoline in Phoenix. As shown in Exhibit C.9, the two models' projections differ dramatically for these fuels. The primary reason for this appears to be the inter-relationship between T50 and T90 in this study. In both the AMOT and Heavy-HC studies, T50 was correlated with T90. However, in the T50-T90 study, the two were varied more independently.

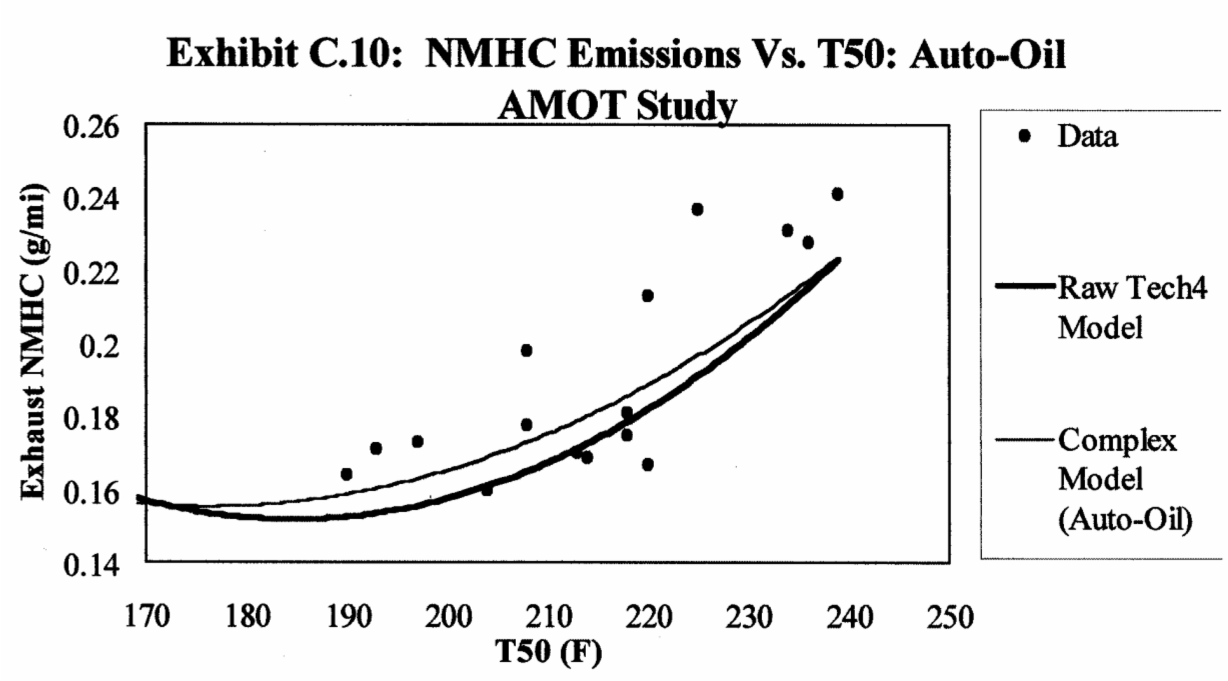
In addition to the correlation between T50 and T90 in the AMOT and Heavy-HC studies, their

Exhibit C.9: Weighted NMHC Emissions Vs. T50: Auto-Oil T50-T90 Study

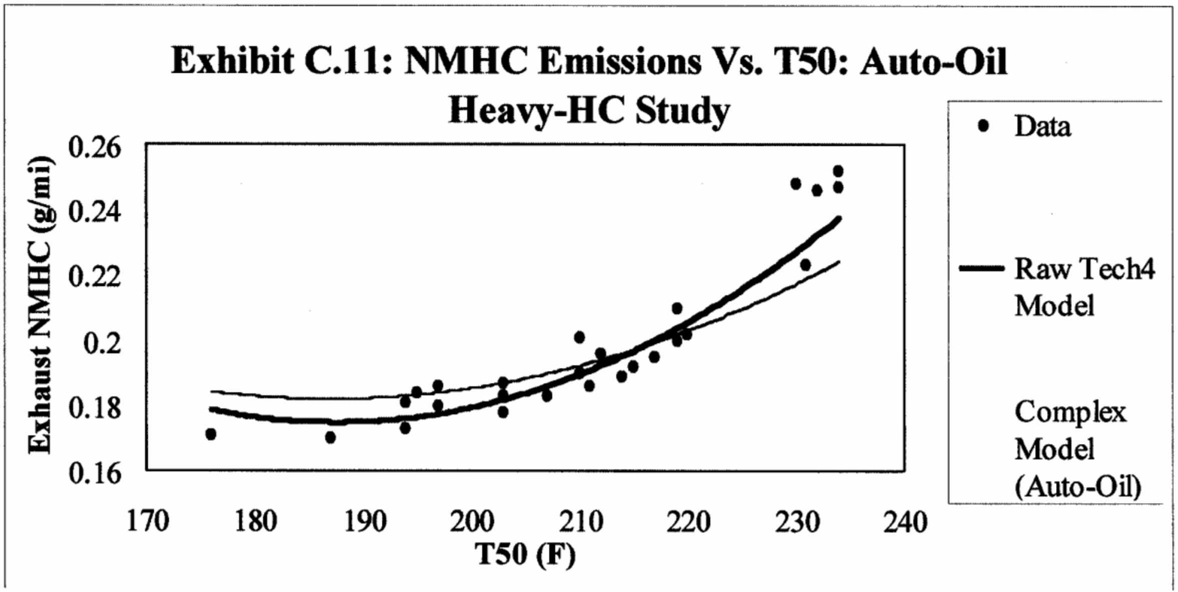


highest levels of T90 (which accompanied the high T50 temperatures) were 340-360^{o}F. Examination of the details of the Complex Model for normal emitters reveals that it includes a strong effect of T90 on exhaust NMHC emissions at high levels of T90, but the effect of T50 on these emissions is relatively flat and does not increase dramatically at high levels of T50. However, the T50-T90 study only included fuels with a maximum T90 temperature of 326^{o}F, but high T50 temperature. This is precisely the combination seen in Phoenix premium gasoline in 1995, which had a T50 of 238^{o}F and a T90 of 338^{o}F. Since the high T50 fuels in the AMOT and Heavy-HC studies also tended to have very high T90 temperatures, the Complex Model projected that these fuels would show dramatic increases in exhaust NMHC emissions. The high T50 fuels in the Heavy HC study tended to have more moderately high T90 temperatures, so the Complex Model projected a less dramatic increase in exhaust NMHC emissions.

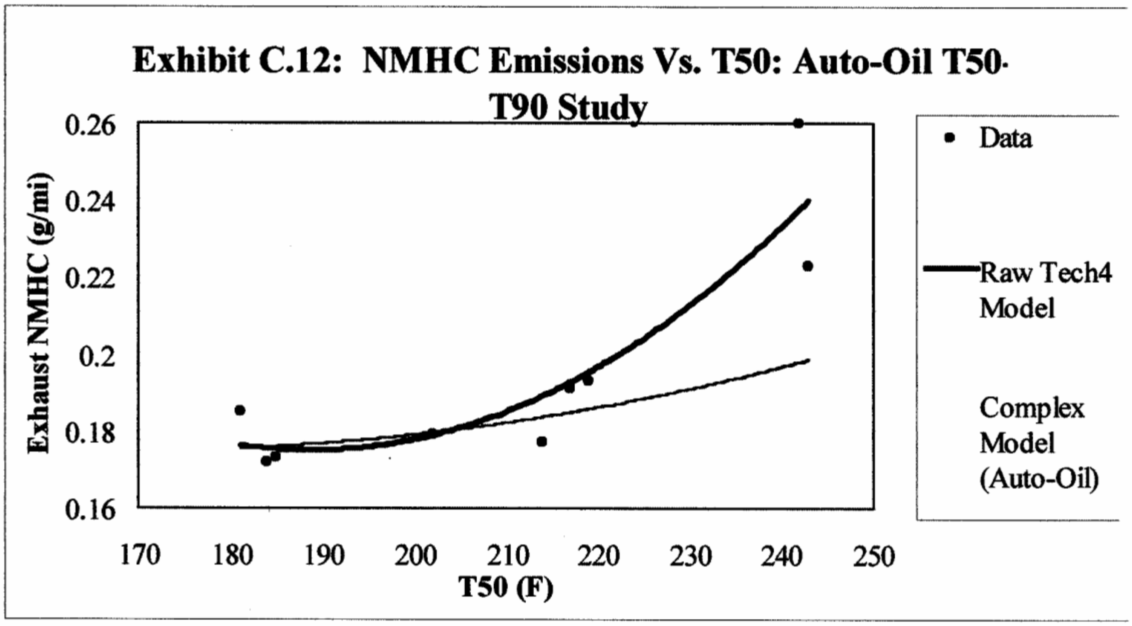
The second set of analyses are depicted in Exhibits C.10 through **C.12**. Here, the terms ofthe Complex Model have been recombined to represent the weighting of the Auto-Oil test fleet, as was described above in the RVP analysis. Again, both models produce similar and reasonable predictions of the AMOT fuels. Thus, the two types of comparisons agree.



In Exhibit C.11, however, the Tech 4 model predicts a larger increase in exhaust VOC emissions with increased T50 than the reweighted Complex Model for the Heavy-HC fuels. Overall, the Tech 4 model comes closer to matching the data. Thus, while both the standard Complex Model and the Tech 4 model both predicted the reweighted data fairly accurately and similarly, the reweighted Complex Model under-estimates the impact of T50 on exhaust VOC emissions at high levels of T50.



In Exhibit C.12, the comparison of the models to the T50-T90 fuels is similar to that depicted in Exhibit C.9. The Tech 4 model is again able to predicts the large increase in exhaust VOC emissions at the high levels of T50. The reweighted Complex Model for the T50-T90 fuels does not predict the dramatic increase in exhaust VOC emissions at high T50 temperatures.



Overall, the Tech 4 model matches the data very well in all six cases. The Complex Model matches the data very well in three out of six cases. In addition, the reweighted Complex Model is able to predict the increase in exhaust VOC emissions shown by the Heavy-HC fuels, though not to quite the data reflected by the data or the Tech 4 model.

The ability of the Predictive Model to predict the high T50 fuels in the T50-T90 study is particularly noteworthy, since this data was not used to develop either model. The data from both the AMOT and Heavy HC studies were used to develop both models, so reasonable fits between the data and the models should be expected. However, the most difficult test of a statistical model is its ability to fit data which was not used in its development. In this case, the Predictive Model more accurately predicts the high T50 fuels of the T50-T90 study.

APPENDIX D

RATIONALE FOR
THE EMISSIONS MODELS OF CHOICE

APPENDIX D: RATIONALE FOR THE EMISSIONS MODELS OF CHOICE

This Appendix provides detailed technical rationale for the choices of emissions models delineated in Section 5.4 of this report.

The discussion presented here is likely to be of interest mainly to those members of the subcommittee who are well-versed in air quality modeling in general and the gasoline certification models in particular.

D.1Exhaust VOC, NOx, and Toxics: On-Road Vehicles

The regulatory version of the Complex Model addresses exhaust emissions of VOC, NOx and air toxics (benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and polycyclic organic material (POM)). Emission impacts are projected separately for *normal emitting* vehicles (generally those vehicles with emissions within a factor of two of their certification standards) and *high emitting* vehicles (generally those vehicles with emissions more than a factor of two above their certification standards). The projections for each type of vehicle are weighted together according to each vehicle type's contribution to in-use emissions to produce a single emission projection.

The Complex Model varies slightly depending on the time period for which it is being used to certify fuels. The Phase 1 model applies to fuels sold prior to 2000, while the Phase 2 model applies in 2000 and beyond. The primary difference between the two models is the version of MOBILE used to form the basis for the baseline emissions in the model (e.g., the breakdown in emissions between normal and high emitters and between exhaust and non-exhaust VOC emissions). A draft version of MOBILE4.1 was used to develop the Phase 1 emissions baseline; MOBILE5a was used for the Phase 2 model. The draft version of MOBILE4.1 used for the Phase 1 Complex Model was never used elsewhere by EPA. Even the final version of MOBILE4.1 has been replaced by MOBILE5a. As described below, MOBILE5a is being used to develop the emission estimates for the urban airshed modelling of Maricopa County, now under way. Thus, the Phase 2 version of the Complex Model is clearly the most up-to-date version of the two models and the most consistent with the urban airshed modelling. Thus, whenever the Complex Model is mentioned, the reference will always be to the Phase 2 model.[1]

The contribution of high emitters to in-use emissions is sensitive to the type of I/M program in place. As Maricopa County has an I/M program equivalent to the enhanced I/M program assumed in EPA's Phase 2 Complex Model, we used the Phase 2 portion of the model in this

[1] There are also distinct Complex Models for northern and southern areas of the U.S. However, these differences only affect non-exhaust VOC and benzene emissions and do not affect the use of the model in this study.

project. The Predictive Model does not distinguish between normal and high emitters, and it is not possible to modify its projections as a function of I/M program. Given that both Maricopa County and much of California both have enhanced I/M, this should not be a problem.

It should be noted that even with enhanced I/M, MOBILE5a (and the Complex Model) still projects that over half of all exhaust VOC emissions will come from high emitters. This is based on extrapolations of I/M testing conducted in South Bend, Indiana. Similar testing conducted in Phoenix was not used, because the vehicles had already been through a basic I/M program. The Phoenix data showed much lower emission levels than the South Bend data and lower emissions than those projected for an enhanced I/M program. Thus, it is possible that MOBILE5a may over-estimate the fraction of high emitters in the Maricopa County vehicle population.

More importantly, while the contribution high emitters to the vehicle fleet changes in MOBILE5a as a function of new vehicle technology and I/M program, the high emitter emission fration in the Complex Model is fixed. Tier 1 vehicles with advanced onboard diagnostic OBD-II systems should perform much better in-use than 1990 technology vehilces. Thus, the Complex Model could overestimate the contribution of high emitters to in-use emissions in future years.

Within the normal emitter class, EPA considered the possibility that various engine and emission control technologies respond to fuel quality differently. Thus, in some cases, vehicles equipped with throttle-body or ported fuel injection will have a different response to a particular fuel parameter than the fleet as a whole. Within the normal emitter group, the projections for vehicles using different technologies are weighted according to the fraction of vehicles sold in the 1990 model year which used that technology and the projected in-use emissions of each technology.

The Complex Model focuses on 1990 model year technology because of a requirement of the Clean Air Act. This requirement applies to the certification of fuels as meeting the RFG requirements. Emission data on vehicles not meeting a strict definition of "1990 technology" were excluded from the database used to develop the Complex Model. This limits the usefulness of the model when attempting to use it to project in-use emission impacts, which inherently affect a vehicle fleet including vehicles from a wide range of model years.

CARB's Predictive Model addresses exhaust VOC, toxic and NOx emissions. It represents two vehicle technology groups. Technology Group 4 (Tech 4) applies to 1986 and later vehicles and is roughly equivalent to the Complex Model's "1990" technology. Technology Group 3 (Tech 3) applies to earlier 1981-85 model year vehicles. Most of these vehicles were equipped with closed-loop, feedback control technology, but tended not to have port fuel injection or adaptive learning. CARB attempted to produce models for even earlier vehicle technology (Tech 1 and 2), but insufficient data were available to accomplish this task.

The Predictive Model does not treat normal and high emitters separately. Their contribution to the model's projections was implicitly based on their contribution to the underlying emission database used to develop the model. Roughly 13% of the vehicles in the database were high emitters for VOC or CO emissions, with the emission contribution being much higher. The Complex Model assumes that roughly 20% of 1990 vehicles are high emitters, contributing 56% of in-use exhaust VOC emissions and 26% of in-use Nox emissions. However, the contribution of high emitters from the future vehicle fleet should be lower than that of the 1990 model year fleet. Thus, the contribution of high emitters in the 2010 fleet, for example, could be somewhere between that implicit in the two models.

One aspect of the Predictive Model's development is relevant to its use in assessing fuel formulation options for Maricopa County. After determining all the fuel parameters that had a statistically significant impact on emissions, CARB simplified the Predictive Model by removing terms that had a small impact on emissions when a variety of fuels were run through the model. For example, a term involving olefins and sulfur might change toxics emissions by less than 0.5% when sulfur and olefins were varied widely. The goal of the simplification process was to maintain most of the model's accuracy while decreasing the number of terms included in it.

In performing this simplication, CARB randomly chose a large number of fuels from the universe of those which could be certified under its RFG program. Such fuels have lower levels of aromatics, olefins, and distillation temperatures than current Maricopa County gasoline, though their sulfur and RVP levels were in line with most Maricopa County fuels. All of the fuel parameters included in the Predictive Model were found to be statistically significant and their impacts were determined using the complete emissions database. This database was the same as that used in developing the Complex Model. Current Maricopa County fuels, as well as those fuel options being considered in this study fall well within the range of gasoline properties in the database. However, the model simplification process focused on much cleaner fuels. It is possible that some fuel factors may have been deleted which play a stronger role in describing the impact of dirtier fuels on emissions than cleaner fuels.

Consequently, we obtained the raw Predictive Model (the model prior to random balance simplification) from CARB and used it in this study. Use of this model should eliminate the possibility that the simplification process biased the model in its prediction of non-California RFG fuels. However, the raw Predictive Model contains more fuel terms than the final model. All of these additional terms were found to have a statistically significant impact on emissons. However, their inclusion in the model was not peer reviewed, because they were dropped from the model through the random balance, simplificatoin step. Thus, the raw Predictive Model cannot be considered to be fully peer reviewed.

The Complex Model went through a similar simplification process. However, the randomly chosen fuels used to evaluate which fuel parameters could be removed included those which could meet the Federal RFG requirements. These requirements allow a far wider range of fuels to be sold than the California RFG requirements. Therefore, the simplification process would have included fuels which are both similar and dissimilar to those currently sold in Maricopa County. For example, the sulfur and RVP levels of current Maricopa County gasoline are much closer to those used to simplify the Predictive Model than those used to simplify the Complex Model, while the olefin and aromatic levels of current Maricopa County gasoline are closer to those used to simplify the Complex Model.

Therefore, from a technical perspective, neither model has a clear analytical advantage for this study, on the basis of the simplification procedures. Overall, the simplification process for both models was intended to remove terms that play a minor role in explaining the effect of fuel quality on emissions. Of course, this does not mean that these terms would not be important in evaluating particular fuel control strategies, only that they were minor across a broad spectrum of fuels. Thus, the simplification processes used on both models raises the possibility that the accuracy of the models were somewhat diminished.

Appendix C presents our evaluation of the Complex Model and the Tech 4 Predictive Model relative to measured emission data. The comparison focuses on only two fuel parameters, RVP and T50. It is not intended as a complete evaluation of the accuracy of either model. However, comparisons of the models to actual emissions data show that the Tech 4 model provides a better explanation of the measured exhaust VOC emission impacts of reduced RVP and T50 than the Complex Model. This increases the desirability of using the Tech 4 Model, as well as the Complex Model, to project emission impacts.

EPA developed the MOBILE5a model to estimate the emissions of an entire fleet of vehicles in various calendar years. MOBILE5a allows the user to select a wide variety of options involving the type of inspection and maintenance (I/M) program operating in the area, if any, the ambient temperature and altitude of the area, the type of refueling emission controls applicable, if any, and a limited number of fuel options. Some of these fuel effects, though limited, differ by model year, a feature not present in the Complex Model.

While either the Complex or Predictive Models are clearly preferable to MOBILE5a for 1986 and later models, the MOBILE5a projections could be used for pre-1986 or pre-1981 model year vehicles. The two fuel parameters with distinct impacts by model year are RVP and oxygenate (not to be confused with oxygen content, since oxygenate's impact on other fuel parameters are included). The primary disadvantage of using the MOBILE5a projections is that they were developed using a much more limited database than either the Complex or Predictive Models. Also, the studies used to develop the MOBILE5a fuel effects were not as carefully designed or performed as most of those used to develop the other two model (e.g., they tended to consistently test fuels in the same order, which can bias the results, etc.).

The relative advantages and disadvantages of using each of these three models to project the emission impacts for various model year groupings are evaluated below.

D.1.1 Late model Tier 0 and Tier 1 vehicles (1986 and later vintage vehicles)

As mentioned above, the Tech 4 model was developed using emissions data from 1986-1992 model year vehicles. The data used to develop the Complex Model was similar, but excluded a number of 1986-1989 vehicles deemed to fall short of "1990" technology. The databases used to develop both models contained information on few, if any, post-1992 vehicles. Emissions control technology used on many post-1992 vehicles did not differ substantially from 1990 technology, but manufacturers did begin to phase in advanced technologies to meet the tighter Tier 1 standards in 1994. Still, both models reasonably represent late Tier 0 technology.

There appear to be no clear reasons why one model should be prefered one over the other. The two models are based on very similar emission data and were developed using very similar statistical techniques. EPA is likely to have a policy-related preference for the Complex Model, as it is an EPA model. The Complex Model also explicitly addresses emissions from high emitters. However, its projections are based on that for the 1990 fleet. Improved in-use emission factors for the use of OBD-II systems in future vehicles are being developed for use in MOBILE6, the successor to MOBILE5a. Thus, this may not be a clear advantage for the Complex Model.

EPA has approved the use of the Predictive Model in estimating motor vehicle emissions in California, as the Predictive Model was used to generate the emission impacts of California RFG-II in EMFAC7g, which in turn was used to estimate the emissions in California's approved SIP. The additional fuel terms included in the raw Tech 4 model appear to help it model changes in T50 and RVP. Thus, use of the Predictive Model appear to add value to the projection of emission impacts in Maricopa County. However, how well the two models perform regarding other fuel parameters has not been evaluated. Thus, we used both models to project the impact of fuel composition on exhaust VOC, NOx and toxic emissions.

The above discussion focused on 1993/94 and earlier vehicles. The issue of the impact of fuel composition on even newer vehicle technology is important, as these vehicles will represent most of the fleet in 2010, the out-year evaluated in this study. Unfortunately, relatively little data exist regarding the effect of fuel quality on the emissions from advanced vehicles.

The Auto-Oil research project has measured the impact of a limited number of fuel parameters (e.g., T50, T90, sulfur and CARB RFG II) on the emissions from some Federal Tier 1 vehicles and prototypes having low-mileage emissions near the California TLEV or LEV standards. Comparison of the sensitivity of both Tier 0 and 1 vehicles to fuel in the Auto-Oil T50, T90, Sulfur program shows that Tier 1 vehicles are more sensitive on a percentage basis to sulfur than Tier 0 vehicles, as measured by the Auto-Oil program. However, the Tier 1 vehicle effect measured by Auto-Oil does not differ substantially from that projected by the Complex Model for normal emitters. Therefore, it is not clear whether the fuel sulfur effects contained in the Complex Model should be adjusted upward for these later vehicles or not. The Tech 4 portion of the Predictive Model projects a greater sensitivity of exhaust VOC emissions to sulfur than the Complex Model. No large differences in the sensitivity to other fuel parameters are apparent within the limited fuels tested in Tier 1 vehicles. Thus, there appears to be no clear evidence that Tier 1 vehicles should be modelled differently than 1986 and later Tier 0 vehicles.

Recent laboratory testing of catalysts and limited vehicle testing has shown that LEV emissions could be much more sensitive to fuel sulfur than Tier 0 vehicles. However, it is not clear when or if LEVs will be sold in Arizona. A number of automobile manufacturers have offered to produce LEVs nationwide beginning in 2001 as an alternative to the LEV program adopted by the Ozone Transport Commission and the individual states in the Northeast. Negotiations over this substitution have been underway for over a year and just recently reached an apparent impasse.

EPA could implement Federal Tier 2 standards for cars and light trucks as early as 2004. Given the automakers' willingness to sell LEVs nationwide beginning in 2001 (albeit as an alternative to the LEV programs of the Northeast states), it appears highly likely that EPA would at least try to implement Tier 2 standards equivalent to the LEV standards beginning in 2004. However, EPA has not yet performed the study of the costs and benefits of the Tier 2 standards which is required by the Clean Air Act prior to implementation of the standards. EPA is also not yet granting states SIP credits for these standards. Thus, it appears premature to address the emissions from LEVs in this study. However, should an agreement be reached on the national LEV program or should EPA decide to implement the Tier 2 standards in 2004, then the recommendations of this study should be reviewed to incorporate the impact of fuels on LEV emissions. Particular attention should be given to the impact of sulfur and any other fuel parameters which appear to have a unique impact on emissions from LEVs.

D.1.2 Early Tier 0 vehicles (1981-1985 model year vehicles)

Model year 1981-1985 light-duty vehicles met the same emission standards as the 1986-1994 vehicles at standard temperatures and low altitude.[2] However, these earlier vehicles tended to be equipped with carburetors and throttle-body fuel injectors and did not have adaptive learning capability, a computer-oriented technique whereby the engine is able to adjust its settings based

[2] High altitude emission requirements became more stringent in 1984 and essentially required the use of feedback controls which could sense the thinner air at high altitude. However, this trend had already been established in the 2-3 previous years.

on previous performance. These vehicles did have computer-controlled, feedback control mechanisms and three-way catalysts.

Light-duty trucks went to 3-way catalysts and feedback controls later than light-duty vehicles. Tight NOx standards equivalent to those applicable to 1981 and later light-duty vehicles were not implemented until 1988 for light-duty trucks. By the 1990 model year, light-duty truck technology had caught up to light-duty vehicle technology for the most part. However, during the 1981-85 period, light-duty truck technology was definitely less advanced than that applied to light-duty vehicles.

For earlier closed-loop vehicles, four options exist. First, the Complex Model could be assumed to apply to these earlier vehicles. Second, the Complex Model could be reconfigured to more closely approximate the pre-1986 vehicle fleet. Third, the Tech 3 portion of the Predictive Model could be used. Fourth, the MOBILE5a impacts for RVP and oxygenate could be used.

The primary advantage of using the Complex Model under the first option is that it is an EPA model, and EPA will be reviewing the Arizona SIP. The disadvantage is that all the available data showing the effect of fuel composition on these vehicles would be ignored in lieu of data on different vehicles. This data shows that the fuel effects in older, carburetted and throttle-body equipped vehicles can differ significantly from those for the more recent vehicles. For example, Auto-Oil testing shows that older vehicles are less sensitive to high levels of T90, apparently due to the longer time available for the fuel to evaporate between the point of induction or injection and the combustion chamber. The carburetor-equipped 1989 vehicle tested by Auto-Oil also showed this lessened sensitivity. Older vehicles are also more sensitive to oxygenate, showing a greater VOC and CO emission reduction with the addition of oxygen to the fuel.

The second option would remove some of this disadvantage in theory. It is possible to determine the overall sales of the nine technology groups addressed by the Complex Model for the 1981-1985 fleet and reweight the model's parameters to reflect these sales. The fuel effects would still be based solely on "1990" technology testing, which included some technologies only applied to post-1985 vehicles, such as adaptive learning. However, at least those fuel effects which differed between the basic fuel management technologies (carburetor, throttle-body injector and port injector) would be better represented.

There are a number of practical problems with this option. One problem is that 44% of 1981-1985 model year sales do not fall into any of the technology groups included in the Complex Model (again ignoring the near absence of adaptive learning prior to 1986 and the requirement that vehicles have this technology in the Complex Model database because of its effect on fuel sensitivity). Nearly 25% of 1981-1985 sales did not even have 3-way catalysts, a technology all vehicles in the Complex Model database had. Finally, two-thirds of the 56% of 1981-1985 vehicles which do match up with one of the 9 technology groups belong to a single group, Technology (Tech) Group 9. Tech Group 9 represents less than 2% of 1990 model year sales. the Complex Model database only includes 70 emission tests of Tech Group 9 vehicles out of a total of more than 2000 total tests. Because of this very small number of tests, Tech Group 9 did not have any unique fuel terms in its model. In other words, a Tech Group 9 model would essentially represent an emissions model for a generic 1990 model year vehicle. Such a model would not reflect the fuel sensitivity of Tech Group 9 vehicles because these vehicles comprised an almost negligible fraction of the overall database.

The third option, using CARB's Tech 3 Predictive Model, has the advantage of being based on actual test data of 1981-1985 model year vehicles. The Tech 3 portion of the Predictive Model was based on 1497 tests of 1981-1985 model year vehicles. Thus, it contains more than 20 times as many emission tests as the Complex Model contains for Tech Group 9 vehicles.

The fourth option, using MOBILE5a, has the advantage again of being consistent with an EPA model in a situation where EPA must approve the benefits contained in the ozone SIP. The disadvantage of this option is that the MOBILE5a fuel effects were based almost entirely on EPA emission factors testing, where vehicles were always tested initially on commercial gasoline, followed by either low RVP or oxygenated fuel. Past experience with the testing of low RVP fuels in EPA's emission factor program during the mid-1980's showed that the sequence of the testing had a significant effect on the results. As mentioned above, MOBILE5a only includes the effects of RVP and oxygenate.

Overall, the preferred option is the Tech 3 Predictive Model for 1981-1985 vehicles. This is satisfactory for VOC, NOx and toxics emissions. However, the Predictive Model does not address CO emissions. The Complex Model and MOBILE5a are the only options available. MOBILE5a only includes the effect of two fuel parameters, RVP and oxygenate. Thus, the Complex Model will be used to model CO emissions from these vehicles.

Because the Complex Model could be used to certify compliance with emission performance standards in Maricopa, the Complex Model will also be used to project the emission impacts of fuel modifications for 1981-1885 vehicles. This will also provide greater insight into the differences in the emission projections of the Predictive and Complex Models, as the Complex Model projections of 1981-1985 vehilces will be coupled with the use of the Complex Model for 1986 and later vehicles. The standard version of the Complex model was used for this purpose. A reweighted model would have differed only slightly from the standard Complex Model and would not have represented the emissions of the technology groups of most interest. Thus, the improvement in predictive capability was not deemed to be worth the required resources.

D.1.3 Pre-1981 vintage vehicles

Regarding pre-1981 vehicles without feedback controls, the only established fuel effects are those contained in MOBILE5a, with the limitations mentioned above. One additional limitation is that the EPA emission factor testing used to develop the effect of RVP on exhaust emissions for these older vehicles generally only included testing down to 9 RVP. This was considered a low RVP at the time this testing was performed, but is well above that being considered in this study. Thus, even the MOBILE5a projections would involve considerable extrapolation.

The other options would be to use either the Complex Model or Tech 3 Predictive Model with those fuel effects known to be inappropriate removed. The one fuel term known to be inappropriate would be the impact of fuel sulfur on NOx emissions. Pre-1981 vehicles had oxidation catalysts which reduced VOC and CO emissions. NOx emissions were not affected by the catalyst. Since sulfur has been clearly shown to only affect catalytic activity and not engine-out emissions, its reduction would not reduce NOx emissions from these vehicles.

None of the available options are ideal. However, the potential for the MOBILE5a effects to be biased by the underlying vehicle test procedures plus the extrapolation of RVP effects from 9 psi to levels below 7 psi argues against this alternative. To maximize consistency with the later model vehicles, both the Tech 3 portion of the Predictive Model and the Complex Model will be used to model VOC, NOx and toxics emissions with the effect of sulfur on NOx emissions removed. The Complex Model will again be used to model the impact of CO emissions.

Non-catalyst, pre-1975 model year vehicles do not need to be modeled, as MOBILE5a only projects emissions from vehicles which are 24 years old or newer. As the earliest calendar year of interest is 1999, only 1975 and later model year vehicles are relevant. If older vehicles were to be modelled, the Tech 3 portion of the CARB Predictive Model would again appear to be the best choice. The effect of sulfur on all emissions (except those involving sulfur itself, such as sulfur dioxide and sulfuric acid, which are discussed below) was removed due to the absence of any type of catalyst on these vehicles.

D.2Non-road Engine Exhaust Emissions

Emissions from new non-road gasoline engines were first regulated with those sold in 1996. The emission control technology used on these just-regulated engines represents that used on on-road vehicles before 1975. Non-road engines are generally equipped with inexpensive carburetors and do not utilize either computer controls or catalysts, due to the low cost of these engines and the equipment they power. EPA is developing a second phase of standards for these engines which will be implemented beginning sometime after 2000. The levels of these standards have not yet been established. It is likely that neither computer-controlled feedback systems, nor catalysts will be required to meet these standards. Thus, non-road engines even well into the future are likely to utilize technology representative of pre-catalyst equipped on-road vehicles.

Very little data exist which demonstrate the impact of fuel quality on the emissions of non-road engines. What data do exist focus on fuels where a large number of fuel parameters are changed at once, such as comparing emissions using a commercial gasoline to an oxygenated gasoline or a Federal or California RFG. To date, this data has not been evaluated to develop a detailed understanding of the role of individual fuel parameters in producing non-road engine emissions.

The mobile source office within EPA has issued limited direction regarding the effect of fuel quality on non-road engine emissions.[3] This direction applies only to the use of Federal Phase 1 RFG. It projects a 3.3% reduction in exhaust VOC emissions for both 4-stroke and 2-stroke engines, based on testing of non-catalyst equipped motor vehicles. This policy has limited usefulness in this study, as Federal Phase 1 RFG is only one of a larger number of fuel options being considered. Also, Federal Phase 1 RFG would only be sold through 1999, being supplanted by Federal Phase 2 RFG in 2000.

More recent test data shows that the effect of Federal Phase 1 RFG on non-road exhaust VOC emissions could be larger. EPA has reported that testing at the Southwest Research Institute found that Federal Phase 1 RFG reduced exhaust VOC emissions from 2-stroke and 4-stroke engines by 12.5% and 1% relative to conventional gasoline, respectively, while testing at the University of Michigan found 5.6% and 6.6% benefits, respectively.[4]

Given the range of fuel options being evaluated in this study and their subtle differences, the best approach to modelling non-road engine emission impacts appears to be an extension of the methodology applied to pre-1981 on-road vehicle emissions. There, both the Complex and the Tech 3 Predictive Models were selected to model VOC, toxic, and NOx emissions, with the impact of sulfur on NOx emissions removed. Given that non-road equipment do not have any catalysts, oxidation or 3-way, the analogous approach would be to use both models with the effect of sulfur removed for all emissions. We used the Complex Model to model CO emission impacts, again with the effect of sulfur removed.

This approach is consistent in principle with EPA's policy, which based its non-road emission benefits on the testing of pre-catalyst on-road vehicles. This approach also allows a distinction to be made between the numerous fuel options being evaluated in this study. Strict application

[3] Lorang, Phil, "VOC Emission Benefits for Nonroad Equipment with the Use of Federal Phase 1 Reformulated Gasoline," EPA memorandum to EPA Regional Air Directors, August 18, 1993.

[4] Lindhjem, Christian E. and William J. Charmley, "The Effect of Fuel Reformulation on 4-Stroke Lawn and Garden Engines," EPA Memorandum to Paul Machiele, July 21, 1994. This memorandum also describes testing performed by EPA which found that Federal Phase 1 RFG reduced exhaust VOC emissions by an average of 4.7%. However, testing on the baseline fuel at the start and end of the test program varied by as much as 20-30%. Therefore, test to test variability or emissions deterioration occurring during the test program appear to be a significant problem in this test program.

of the EPA policy would only apply a benefit to Federal Phase 1 RFG (and, due to their similarities, Federal and California Phase 2 RFGs). The approach recommended here yields emission projections which compare reasonably well with limited testing of non-road emissions. For example, Federal Phase 1 RFG is projected here to reduce non-road exhaust VOC emissions by 4.6% and 7.1% relative to Clean Air Act Baseline gasoline using the Complex and Predictive Models, respectively. These emission impacts fall well within the range of the above testing. Per current EPA policy, these impacts will be applied equally to both 2-stroke and 4-stroke engine emissions.

There is a technical issue involved in removing the sulfur effect on exhaust VOC emissions from the Tech 3 model. The Tech 3 model includes a sulfur-aromatics interactive term. Sulfur generally only affects catalyst performance, not engine out emissions of non-sulfur containing pollutants. Thus, this effect should be removed from the model. This is usually done by holding the sulfur level constant. However, in this case, the effect of aromatics on emissions changes depending on the sulfur level chosen. Based on discussions with the Subcommittee, it was decided that the sulfur level should be fixed at the current average sulfur level for Maricopa County, as estimated in the refining analysis: 164 ppm.

This use of on-road vehicle emission models with sulfur effects removed is approximate at best and should be viewed as having a substantial degree of uncertainty. Still, given the sizeable contribution of non-road equipment to the VOC emission inventory in Maricopa County, the potential fuel impacts should be estimated in the best possible manner. It is unlikely that substantial amounts of new emissions data will be developed in the near future that would allow better estimates to be made.

Given that little data are available on the emissions of air toxics from non-road equipment, no estimates were made of baseline or adjusted emissions of air toxics from non-road equipment.

D.3Non-exhaust VOC and Benzene Emissions

The Complex Model projects both non-exhaust VOC and benzene emissions. The Predictive Model does not address non-exhaust emissions, so it is not applicable here. The data used to project non-exhaust VOC emissions in the Complex Model was taken straight from MOBILE5a and are solely a function of RVP. The Phase 2 non-exhaust VOC model was developed using projections of the impact of fuel RVP from MOBILE5a assuming enhanced I/M and Stage II refueling controls were in place. Slightly different ambient temperatures were assumed for southern and northern U.S. cities (i.e., Class B and C RFG), respectively. The temperatures for each area were based on a population-weighted analysis of the high ozone day temperatures typical for RFG cities.

Temperatures typical of high ozone days in Maricopa County are much higher than those assumed in developing the Complex Model, even the portion of the model designed for Class B RFG areas in the southern portion of the U.S. Consequently, we did not use the Complex Model for non-exhaust VOC emissions. Instead, we used MOBILE5a to model the impact of fuel RVP on non-exhaust emissions. This is fully consistent with the development of the Complex Model, as the Complex Model for non-exhaust VOC emissions contains no information beyond that contained in MOBILE5a.

The Complex Model for non-exhaust benzene emissions was developed by analyzing non-exhaust benzene emission data in terms of its fraction of non-exhaust VOC emissions. Thus, the primary value of the Complex Model in this area is its ability to project the effect of fuel quality on the benzene fraction of non-exhaust VOC emissions. We used the Complex Model here in just this way. We analyzed each fuel formulation option with the Complex Model to determine

the benzene fraction of non-exhaust VOC emissions. We then applied this fraction to the estimate of non-exhaust VOC emissions obtained from MOBILE5a.

No established models exist which project the effect of RVP on non-exhaust VOC emissions from non-road engines. These engines do not have any evaporative emission controls, and so are similar to on-road vehicles prior to the use of evaporative emission controls or to vehicles whose controls have been disabled or have failed. The MOBILE5 algorithms for such vehicles could be used to estimate the impact of RVP on these emissions. However, even this would involve a significant number of assumptions, since the carburetor and fuel tank designs of non-road equipment differ substantially from on-road vehicles.

Estimates of non-exhaust VOC emissions from non-road engines are generally quite low relative to exhaust VOC emissions. This limits the potential emission benefits which are available from their control and the need to precisely project their level. Therefore, an approximate estimate appears to be satisfactory. The non-exhaust VOC emissions from non-road equipment will be assumed to change by the same percentage as those emissions from on-road vehicles. This should be at least as accurate as the projection of exhaust emission impacts from non-road engines and should be satisfactory for the purposes of this study.

D.4 Ozone-Forming Potential

The primary model used to project the impact of vehicle emissions on ambient ozone levels is the Urban Airshed Model. The state of Arizona is currently conducting a new study of the Maricopa County airshed using that model. While the Clean Air Act places a number of requirements on states regarding the total mass of VOC emissions, states are also required to use the Urban Airshed Model in their attainment demonstrations. This model groups the various species of VOC emissions into reactivity categories, usually using what is known as the carbon-bond mechanism. Therefore, the relative reactivity of VOC emissions is directly factored into the demonstration of attainment through the use the Urban Airshed Model.

The Auto-Oil program also used this model to estimate the impact of a number of fuel quality modifications on ambient ozone levels in Dallas, New York and Los Angeles. Auto-Oil also estimated these ozone impacts using various estimates of the relative ozone reactivities of the VOC emissions associated with the various fuels. They compared the changes in the ozone-forming potential of VOC emissions (OFP) to the results of running the Urban Airshed Model and found very good agreement between the two approaches. The agreement was particularly good in those areas where VOC emissions are the limiting factor in ozone formation, which is expected to be the case for Maricopa County.

Because of time and resource constraints, we simplified the methodology for reactivity-weighting VOC emissions. The largest impact on the ozone reactivity of VOC emissions from vehicles is usually the relative fraction of exhaust and non-exhaust VOC emissions. Non-exhaust emissions primarily reflect the composition of the lighter fuel components and are dominated by lighter paraffins with a relatively low ozone reactivity. Therefore, fuel options which focus on non-exhaust emissions will likely produce less ozone benefit per mass of VOC reduced than those focusing on exhaust emissions.

Auto-Oil estimated that the ozone-forming potential (OFP) of exhaust VOC emissions using 1990 national average gasoline was approximately 3.5 g ozone per g non-methane organic gases (NMOG, which approximates VOC), while that for non-exhaust VOC emissions was approximately 2 g ozone per gram VOC. We used these average OFPs to estimate the effect of the fuel options on total OFP in this study.

D.5 Particulate Emissions

No equivalent to the Complex and Predictive Models exists for addressing the impact of fuel composition on particulate emissions from gasoline-fueled vehicles. Far too little data exists to develop such a model. However, EPA has developed a simplified version of its MOBILE5a model to project fleet-wide emissions of particulate matter from motor vehicles, called PART5.

PART5 includes three fuel-related effects. First, emissions of sulfur-containing compounds (e.g. sulfur dioxide and sulfuric acid) are projected as proportional to fuel sulfur content. (PART5 does not allow the user to modify fuel sulfur content, but PART5 adjusts the emissions of sulfur-containing emissions for changes in fuel sulfur content which it projects will occur.) Second, emissions of carbonaceous PM are assumed proportional to exhaust VOC emissions when reformulated gasoline is used. Third, lead emissions are assumed proportional to fuel lead content, which is not relevant to this study.

Because the sulfur content of Maricopa County's current gasoline pool and the various baseline fuel formulation options contain less sulfur than the national baseline (339 ppm), we adjusted the emissions of sulfate PM as projected in PART5 by the ratio of the sulfur content in the fuel being considered to that assumed in PART5, generally 339 ppm.

Emissions of carbonaceous PM for current Maricopa County gasoline were assumed to be that projected by PART5 for non-reformulated gasoline. PM emissions for the control fuels were assumed proportional to exhaust VOC emissions. Based on previous analyses of the available PM emission data performed by AIR, the PART5 emission factors for carbonaceous PM emissions from post-1980 model year vehicles are probably low. Thus, the PM emission benefits projected herein are also expected to be lower than are likely to occur.

EMFAC7g, CARB's equivalent of the MOBILE5a model, also projects particulate emissions. However, it has essentially adopted the PART5 emission factors as its inputs, so no additional insight would be obtained by including it in this study.

PART5 addresses exhaust PM emissions plus sulfate PM formed later in the atmosphere from directly emitted sulfur dioxide. Reduced fuel sulfur levels will reduce sulfur dioxide emissions and thus, secondary sulfate PM formed from these emissions in the atmosphere. The impact of reduced fuel sulfur levels on secondary sulfate PM will be included in this study and taken from the PART5 estimates adjusted for fuel sulfur level. However, PART5 does not include secondary organic PM formed from VOC emissions.

A number of studies in the peer-reviewed literature have addressed this issue. Estimates of ambient carbonaceous PM levels are available for the Maricopa County area, in particular. Separating ambient organic aerosol into that which was directly emitted and that which was formed in the atmosphere is not easily done. While estimates of the amount of secondary organic PM produced from various VOCs are available, they have not been able to be directly compared with ambient measurements of secondary organic aerosol, only total organic aerosol. Also, time and resource constraints prevented us from projecting speciated VOC emission profiles for each of the fuel options being considered. Therefore, we did not make quantitative estimates of the effect of VOC emission reductions on secondary organic aerosol.

The primary source of PM estimates was the recent work of Bowman, Pilinis and Seinfeld (cited in Section 5.4 of the report). This work shows that heavier aromatics and olefins (i.e., those above 8 carbon atoms per molecule) have the greatest propensity to form carbonaceous aerosol in the atmosphere. Heavy paraffins comprise the category of VOCs with the second highest propensity to form carbonaceous aerosol. Gasoline engines do not form heavier VOCs from lighter fuel components through the combustion process. Lighter compounds are formed from heavier fuel components, but not vice versa. Thus, heavier fuels are more likely to produce heavy VOC emissions. Here, a significant decrease in a fuel's E300 would be judged to significantly reduce secondary organic aerosol and vice versa.

Aromatics in the exhaust are produced almost entirely from aromatics in the fuel. Olefins in the exhaust, on the other hand, can be produced from paraffinic and aromatic fuel components, as well as olefins. However, olefinic fuel components will have a greater probability of being emitted as olefins than either of the other two components. Thus, we assumed that significant decreases in olefin or aromatic content would significantly decrease secondary organic aerosol, and vice versa.
Overall, then, three factors will determine this study's projection of a fuel's overall propensity to produce secondary organic aerosol: E300, aromatic content and olefin content.

D.6 Toxics-Related Cancer Impacts

The air toxics included in the Predictive and Complex Models have significantly different potencies. It is also possible that various fuel formulation options would increase some toxic emissions and decrease others. Factoring in their relative cancer forming potencies allows a single total cancer forming potency to be used. Without combining the toxic emissions with population exposure, this single potency estimate is somewhat arbitrary and is primarily useful for comparison purposes. To give this overall potency more relevance, we calculated it on a benzene equivalent basis. That is, non-benzene toxic emissions were multiplied by the ratio of their toxicity to that of benzene. These benzene-equivalent emissions were then summed across all the air toxics. This was done using both the EPA and CARB potencies. The primary difference between the two sets of potencies concerns that for benzene. EPA's benzene potency is based on human epidemiological studies and is lower than the CARB potency, which is based on animal testing. Thus, the potencies of the non-benzene toxics relative to the potency of benzene is higher for the EPA potencies than the CARB potencies.

The EPA and CARB potencies for air toxics relative to benzene are shown in **Exhibit D.1**.

Exhibit D.1: Toxic Potencies Relative to Benzene		
	ARB Potency	EPA Potency
Benzene	1.00	1.00
Butadiene	5.88	33.64
Formaldehyde	0.21	1.59
Acetaldehyde	0.09	0.14

APPENDIX E

DETAILED RESULTS OF THE REFINING ANALYSIS

**Exhibit E-1.1: East Notional Refinery: Modeling Results --
Crude Oil Inputs, Process Unit Utilization, Additions, and Operations, by Fuel Formulation Option**

Refining Processes	Notional Refinery Capacity	Fuel Formulation Option							
			Federal RFG			California		Low	10% VOC
		Current	Phase 1	Phase 1/7.8 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Crude Oil Input (M b/d)		57.7	56.4	56.5	56.6	55.6	57.8	57.8	56.5
Existing Capacity (M b/d):									
Fluid Cat Cracker	19.2	19.2	17.6	18.1	17.9	18.3	18.8	19.2	18.1
Coking - Delayed	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Alkylation	7.1	5.1	4.8	4.8	4.9	5.7	5.0	5.1	5
Reforming - Low pressure	13.0	8.7	7.5	7.5	7.5	6.6	8.6	8.7	6.8
Reforming - High pressure	3.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.1
Deep Distillate Desulfurization	*0.7*	0.7	7.0	0.7	0.7	0.7	0.7	0.7	0.7
Distillate Desulfurization	*15.7*	15.7	15.7	15.7	15.7	15.6	15.7	15.7	15.7
Reformer Feed Desulfurization	18.3	9.0	9.2	9.2	9.3	9.0	9.5	9.1	9.1
C4 Isomerization	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Debutanization	*2.1*	2.1	1.9	2.0	2.1	2.1	2.1	2.1	2.1
New Capacity (M b/d):									
FCC Gasoline Desulfurization					0.8	0.7	0.9		
FCC Gasoline Splitter #1					1.0	3.2	3.2		
FCC Gasoline Splitter #2						0.7			
FCC Gasoline Splitter #3						0.9			
Heavy Naphtha Splitting									2.5
Benzene Removal			0.05	0.05	0.05	0.06			
Debutanization		0.1					0.1	0.2	
Operating Indices:									
FCC Conversion (vol %)		73.3	72.5	72.8	73.1	76.6	73.3	74.8	74.3
Reformer Severity (RON)		100.9	97.1	97.3	97.2	94.7	99.8	100.9	97.2
Charge Rates (M b/d):									
Fluid Cat Cracker		19.0	18.5	18.6	18.6	18.5	19.5	19.1	18.6
Reformer - Low pressure		7.1	7.3	7.2	7.3	7.1	7.3	7.2	6.0
Reformer - High pressure		1.9	2.0	2.0	1.9	2.0	1.9	1.9	3.1

Note: Italics indicates ARMS added some or all of capacity in the base case.

Exhibit E-1.2: East Notional Refinery: Modeling Results -- Gasoline Properties and Composition, by Fuel Formulation Option

Property & Composition	Anti-Dumping Baseline	Fuel Formulation Option							
		Current		Phase 1 RFG		Phase 1 RFG, 7.0 RVP		Phase 2 RFG	
		Conv.	Maricopa	Conv.	Maricopa	Conv.	Maricopa	Conv.	Maricopa
Property:									
RVP (psi)	8.7	8.7	6.7	8.7	7.2	8.7	6.7	8.7	6.7
Oxygen (wt%)	0.2	0.0	0.0	0.0	2.1	0.0	2.1		2.1
Aromatics (vol%)	32.4	33.0	31.0	32.4	23.6	32.4	24.3	32.3	25.0
Benzene (vol%)	2.38	2.65	1.71	2.40	0.95	2.40	0.95	2.40	0.95
Olefins (vol%)	11.8	12.0	9.3	11.8	11.1	11.8	11.1	11.8	8.0
Sulfur (ppm)	364	359	370	364	270	364	270	364	170
T50*	209.4	208.2	216.2	210.3	195.6	210.5	196.7	209.8	198.3
T90*	326.1	323.9	332.7	322.1	321.0	321.3	324.8	322.5	322.2
E200	45.3	45.9	42.0	44.8	52.0	44.8	51.5	45.1	50.8
E300	83.7	84.2	82.3	84.6	84.8	84.8	84.0	84.5	84.6
Energy Den. (MMbtu/b)	5.22	5.23	5.24	5.23	5.05	5.23	5.07	5.23	5.07
Composition (vol %)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	6.5	6.3	3.7	6.4	3.2	6.5	2.4	6.5	2.1
Butenes	0.6	0.1		0.0					
I-Butane	5.0	5.0	3.7	6.4	0.9	6.5	0.4	6.4	
N-Butane	0.9	1.3			2.3		2.0	0.1	2.1
C5s & Isomerate									
Raffinate					0.4	0.2		0.2	
Naphtha:	12.4	11.9	13.3	9.7	13.1	9.0	15.0	8.5	15.6
C5 - 160	10.7	11.7	8.4	9.4	13.1	9.0	14.2	8.5	15.6
Coker Naphtha	0.2	0.3		0.2	0.0				
160 - 250	1.5		4.9				0.8		
Alkylate	16.4	15.3	22.4	14.9	20.6	15.2	19.5	14.0	23.4
FCC Gasoline:	39.1	39.1	39.0	40.0	29.3	40.6	28.9	43.5	21.4
Full Range	39.1	39.1	39.0	40.0	29.3	40.6	28.9	41.2	18.1
Medium								0.2	
Heavy									
Medium - Desulf.								2.2	
Heavy - Desulf.									3.3
Reformate:	25.7	27.3	21.6	29.1	21.9	28.5	22.7	27.3	26.0
Light Ref.	13.4	16.9	5.0	20.3	1.5	20.3	0.7	19.7	2.9
Heavy Ref.	12.2	10.5	16.6	8.8	20.4	8.2	22.0	7.6	23.1
Oxygenate					11.5		11.5		11.5
Gasoline Vol. (M b/d)	28	20	8	20	8	20	8	20	8

* Based on EPA formulas:
T50 = (147.91 - E200) / 0.49
T90 = (155.47 - E300) / 0.22

Exhibit E-1.2: East Notional Refinery: Modeling Results -- Gasoline Properties and Composition, by Fuel Formulation Option

Property & Composition	Fuel Formulation Option							
	California RFG		Task Force		Low RVP		10% VOC Reduction	
	Conv.	Maricopa	Conv.	Maricopa	Conv.	Maricopa	Conv.	Maricopa
Property:								
RVP (psi)	8.7	6.7	8.7	6.7	8.7	6.2	8.7	6.5
Oxygen (wt%)	0.3	2.2		0.0		0.0	0.3	1.2
Aromatics (vol%)	33.0	18.3	32.2	33.0	32.2	33.0	31.4	28.3
Benzene (vol%)	2.4	0.8	2.50	2.21	2.76	1.44	2.3	2.4
Olefins (vol%)	12.0	0.6	12.0	10.4	12.0	9.6	11.8	9.3
Sulfur (ppm)	370.0	30.0	370	116	359	370	360.0	307.6
T50*	210.0	194.4	208.6	216.1	209.2	214.7	208.2	199.5
T90*	323.7	284.0	321.2	320.6	320.0	343.0	324.0	304.9
E200	45.0	52.6	45.7	42.0	45.4	42.7	45.9	50.2
E300	84.3	93.0	84.8	84.9	85.1	80.0	84.2	88.4
Energy Den. (MMbtu/b)	5.22	5.01	5.22	5.26	5.22	5.26	5.20	5.14
Composition (vol %)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	7.0	1.3	6.5	3.0	6.6	2.4	6.4	2.4
Butenes								
I-Butane	6.8		5.2	3.0	5.3	2.4	6.4	0.3
N-Butane	0.3	1.3	1.2		1.3			2.1
C5s & Isomerate								
Raffinate		0.4						
Naphtha:	7.3	17.2	10.5	12.2	11.8	13.4	10.5	12.8
C5 - 160	7.2	17.2	10.2	12.2	9.8	13.1	9.8	12.2
Coker Naphtha			0.3		0.3		0.2	0.1
160 - 250	0.1				1.7	0.3	0.5	0.5
Alkylate	9.2	43.1	15.9	20.4	16.4	20.1	14.4	20.3
FCC Gasoline:	45.4	7.8	45.3	23.0	38.5	40.6	39.3	33.3
Full Range	38.5		38.3	11.2	38.5	40.6	39.3	33.3
Medium	6.9	0.3	3.9	9.5				
Heavy								
Medium - Desulf.								
Heavy - Desulf.		7.5	3.1	2.3				
Reformate:	29.6	18.1	21.8	41.3	26.7	23.6	27.6	24.4
Light Ref.	16.0	9.6	16.5	10.7	17.6	3.5	13.3	15.8
Heavy Ref.	13.6	8.5	5.3	30.7	9.1	20.1	14.3	8.5
Oxygenate	1.4	12.1					1.7	6.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Exhibit E-1.3: East Notional Refinery -- Changes in Refining Cost and Revenue, by Fuel Formulation Option

	Fuel Formulation Option						
	Federal RFG			California		Low	10% VOC
Measure	Phase 1	Phase 1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Investment ($MM)	1.8	1.9	6.7	10.9	4.6	-0.3	1.8
Cost ($M/d)							
Input cost	9.6	10.4	11.6	12.5	1.9	1.0	8.9
Variable cost	-0.4	-0.4	0.1	0.9	0.8	0.2	-0.4
Capital Recovery	2.5	2.8	10.1	19.7	9.2	0.5	4.4
Product Revenue ($M/d)	-3.2	-2.5	-2.7	-9.3	-3.2	0.5	-5.5
Net Cost ($M/d)	14.9	15.3	24.5	42.4	15.1	1.2	18.4

Exhibit E-1.4: East Notional Refinery: Modeling Results -- Changes in Crude Oil Inputs, Other Inputs, and Refined Product Outputs
(M barrels/day)

Inputs/ Outputs	Price ($/bbl)	Fuel Formulation Option							
		Current	Federal RFG Phase 1	Federal RFG Phase1/7.0 RVP	Federal RFG Phase 2	California RFG	GAPEP	Low RVP	10% VOC Reduction
Crude Oil		57.7	-1.3	-1.2	-1.1	-2.1	0.1	0.1	-1.3
Domestic Composite	20	57.7	-1.3	-1.2	-1.1	-2.1	0.1	0.1	-1.3
Other Inputs		1.3	1.0	0.9	0.9	1.8	-0.0	-0.0	0.9
Isobutane	18	1.3	0.08	0.02	-0.03	0.52	-0.01	-0.02	0.04
MTBE	39.9	0.0	0.9	0.9	0.9	1.3	-	-	0.9
Refined Products		58.2	-0.23	-0.18	-0.20	-0.55	-0.20	0.03	-0.34
Coker Naphtha	13	0.0	-	0.05	0.05	0.06	-	-	-
BTX	10	0.0	0.05	0.05	0.05	0.05	-	-	-
Propane	20	1.6	-0.12	-0.13	-0.10	-0.16	-0.04	0.00	-0.10
Butane	17	0.0	-	-	-	-	-	-	-
Maricopa Co. Gasoline	-	8.0	-	-	-	-	-	-	-
Conventional Gasoline	-	20.0	-	-	-	1.00	-	-	-
Jet Fuel	-	4.3	-	-	-	-	-	-	-
Diesel Fuel	-	12.0	-	-	-	-	-	-	-
Distillate - High Sulfur	-	5.0	-	-	-	-1.00	-	-	-
Resid - Low Sulfur	15	1.1	-0.05	-0.05	-0.11	-0.12	-0.12	0.12	-0.12
Resid - High Sulfur	13	3.0	-0.11	-0.11	-0.10	-0.39	-0.05	-0.10	-0.12
Asphalt	12	3.0	-	-	-	-	-	-	-
Coke	0.8	0.2	-	-	-	0.01	0.01	0.01	-
Sulfur	27	0.03	-	-	-	-	-	-	-

Exhibit E-2.1: West Notional Refinery: Modeling Results – Crude Oil Inputs, Process Unit Utilization, Additions, and Operations, by Fuel Formulation Option

Refininig Processes	Notional Refinery Capacity	Fuel Formulation Option							
		Current	Federal RFG Phase 1	Federal RFG Phase1/7.0 RVP	Federal RFG Phase 2	California RFG	GAPEP	Low RVP	10% VOC Reduction
Crude Oil Input		150.9	149.2	149.3	149.7	148.4	151.0	150.6	150.9
Existing Capacity (M b/d):									
Fluid Cat Cracker	54.7	41.7	41.2	41.2	41.2	39.1	41.3	41.6	40.8
Hydrocracker - Dist. Feed	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
Hydrocracker - Gas Oil. Feed	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Coking - Delayed	48.9	42.5	42.1	42.1	42.4	44.0	42.8	42.3	43.7
Alkylation	*13.4*	13.4	12.9	12.9	13.2	13.3	13.3	13.3	13.4
Cat. Polymerization	0.4	-	-	-	-	-	-	-	-
C5/C6 Isomerization (tot. recycle)	2.6	2.6	1.3	1.3	1.7	2.3	2.6	2.4	2.6
Reforming (150-350 psi)	37.4	28.5	28.4	28.4	28.1	27.6	28.5	28.8	27.8
MTBE Plant	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Deep Distillate Desulfurization	*13.8*	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
Distillate Desulfurization	28.3	28.2	28.0	28.0	28.3	28.3	27.8	28.1	27.3
FCC Feed Desulfurization	54.7	36.8	36.2	36.3	36.3	34.3	36.7	36.8	35.9
FCC Gasoline Desulfurization	*9.2*	9.2	9.2	9.2	8.7	9.2	9.2	9.2	8.6
Naphtha & Isom Feed Desulf.	open	7.0	5.9	5.9	6.2	7.3	7.3	6.9	7.3
Reformer Feed Desulfurization	32.6	18.0	17.5	17.6	17.7	17.4	17.8	17.8	17.9
Resid Desulfurization	2.1	-	-	-	-	-	-	-	-
FCC Gasoline Splitter #1	*20.6*	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6
FCC Gasoline Splitter #2 (C5s)	*0.6*	0.6	0.3	0.4	0.6	0.6	0.4	0.5	0.6
Benzene Removal	*4.4*	4.4	4.4	4.3	4.4	4.4	4.4	4.4	4.4
C4 Isomerization	1.1	1.1	1.1	1.1	1.1	0.8	1.1	1.1	1.1
Debutanization	*11.7*	11.7	11.2	11.2	11.2	10.7	11.5	11.5	11.5
Hydrogen Plant	*3.9*	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
New Capacity (M b/d):									
FCC Gasoline Splitter #1						0.8			
FCC Gasoline Splitter #2					0.2	1.0			
Benzene Removal									0.2
Operating Indices:									
FCC Conversion (Vol %)		79.2	78.5	78.5	78.3	77.7	79.9	79.2	79.9
Reformer Severity (RON)		99.6	100.0	100.0	99.9	100.0	99.9	100.0	99.8
Charge Rates (M b/d):									
Fluid Cat Cracker		41.4	40.9	41.0	40.9	38.9	41.1	41.4	40.5
Reformer (150-350 psi)		23.3	22.9	22.9	22.8	22.3	23.1	23.3	22.7

Note: Italics indicates ARMS added some or all of capacity in the base case.

Exhibit E-2.2: West Notional Refinery: Modeling Results – Gasoline Properties and Composition, by Fuel Formulation Option

Property & Composition	Anti-Dumping Baseline	Fuel Formulation Option: Current		Phase 1 RFG			Phase 1 RFG, 7.0 RVP			Phase 2 RFG		
		Cal RFG	Maricopa	Cal RFG	Maricopa	Conv.	Cal RFG	Maricopa	Conv.	Cal RFG	Maricopa	Conv.
Property												
RVP (psi)	8.2	6.7	6.7	6.7	7.1	8.7	6.7	6.7	8.7	6.7	6.6	8.7
Oxygen (wt%)	0.0	1.8	0.0	1.8	2.1	0.0	1.8	2.1	0.0	1.8	2.1	0.0
Aromatics (vol%)	35.2	23.0	37.0	22.8	34.0	37.0	23.0	34.0	35.6	23.0	28.6	37.0
Benzene (vol%)	2.14	0.70	1.10	0.70	0.95	1.10	0.70	0.95	1.10	0.70	0.95	1.10
Olefins (vol%)	13.3	4.0	10.5	4.0	10.5	10.5	4.0	10.5	10.5	4.0	10.5	10.5
Sulfur (ppm)	135.4	30.0	90.0	30.0	90.0	90.0	30.0	90.0	90.0	30.0	90.0	90.0
T50*	215.2	193.7	*232.0*	192.8	212.4	*232.0*	193.7	206.7	*230.5*	193.7	205.9	*232.0*
T90*	337.8	*300.0*	*335.0*	297.6	335.5	*335.0*	297.6	335.5	*335.0*	297.6	315.8	*335.0*
E200	42.4	53.0	35.4	53.4	43.8	35.4	53.0	46.6	35.7	53.0	47.0	35.4
E300	81.1	90.0	79.0	90.0	81.7	79.0	90.0	81.7	79.0	90.0	86.0	79.0
Energy Den. (MMbtu/b)	5.25	5.08	5.30	5.08	5.15	5.27	5.08	5.15	5.27	5.08	5.12	5.28
Composition (vol %)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	5.5	1.8	5.6	1.8	5.4	8.1	2.0	3.8	8.0	1.9	4.0	8.6
Butenes	4.1											
I-Butane	1.5		2.5		0.8	7.4	0.5		4.3	0.4	1.0	1.2
N-Butane		1.8	3.1	1.8	4.6	0.7	1.5	3.8	3.7	1.5	3.0	7.4
C5s & Isomerate		3.5		1.8			1.8			2.3		
Natural Gas Liquids	1.5											
Naphtha:	7.5	11.1	3.4	12.1	11.9	0.3	11.2	15.6	4.3	11.4	10.8	4.2
C5 - 160	5.1	7.0		8.7		0.0	8.3	2.9		7.5	5.7	
Coker Naphtha	2.4											
160 - 175												
160 - 250		4.1	3.4	3.4	11.9	0.3	2.8	12.7	4.3	3.9	5.1	4.2
Alkylate	10.4	19.2	5.2	19.3	1.8	0.7	18.4	2.0	8.3	19.3	0.8	6.9
Poly Gas	0.3											
Hydrocrackate	9.5	15.2	1.9	14.5		10.9	15.0		6.9	15.2	1.8	4.5
FCC Gasoline:	35.3	19.8	56.8	19.9	42.4	65.9	21.1	37.9	60.8	18.3	60.6	59.4
Full Range	35.3	1.4	19.3	2.7	23.4	6.5	1.7	28.2	9.6	3.1	8.0	12.6
Light		4.6	6.7	4.9	7.2	3.2	4.5	7.8	5.8	4.5	7.4	5.6
Medium		5.6	14.6	3.8	7.7	30.0	5.7		23.0	3.9	27.5	20.7
Medium - Desulf.		1.2	14.1	4.2	0.1	6.2	5.0			3.0	6.2	2.6
Heavy - Desulf.		7.0	2.1	4.3	4.0	20.0	4.3	1.9	22.5	3.8	11.6	18.3
Reformate:	29.9	19.5	27.2	20.7	27.0	14.1	20.8	29.2	11.6	21.7	10.5	16.4
Light Ref.	8.9	6.2	2.4	6.1	0.7	3.1	5.9	2.1	3.4	5.7	1.6	5.1
Heavy Ref.	21.0	13.3	24.7	14.6	26.3	11.0	14.8	27.0	8.2	16.0	9.0	11.3
Oxygenate		9.9		9.9	11.5		9.9	11.5		9.9	11.5	
Gasoline Vol. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* Based on EPA formulas:
$T50 = (147.91 - E200) / 0.49$
$T90 = (155.47 - E300) / 0.22$
Note: Italics indicate that the T50 or T90 was estimated using ARMS generated distillation curves, rather than EPA's formulas.

Exhibit E-2.2: West Notional Refinery: Modeling Results – Gasoline Properties and Composition, by Fuel Formulation Option

Property & Composition	Fuel Formulation Option										
	California RFG		GAPEP			Low RVP			10% VOC Reduction		
	Cal RFG	Conv.	Cal RFG	Maricopa	Conv.	Cal RFG	Maricopa	Conv.	Cal RFG	Maricopa	Conv.
Property											
RVP (psi)	**6.7**	**8.7**	**6.7**	**6.7**	**8.7**	**6.7**	**6.2**	**8.7**	**6.7**	**6.5**	**8.7**
Oxygen (wt%)	**2.0**	**0.0**	**1.8**	**0.0**	**0.0**	**1.8**	**0.0**	**0.0**	**1.8**	**0.5**	**0.0**
Aromatics (vol%)	**23.0**	**37.0**	**22.9**	**36.2**	**37.0**	**23.0**	**37.0**	**37.0**	**22.6**	**31.0**	**37.0**
Benzene (vol%)	**0.70**	**1.10**	**0.70**	**1.10**	**1.10**	**0.70**	**1.10**	**1.10**	**0.70**	**1.10**	**1.10**
Olefins (vol%)	**4.0**	**10.5**	**4.0**	**10.5**	**10.5**	**4.0**	**10.5**	**10.5**	**4.0**	**10.5**	**10.5**
Sulfur (ppm)	**30.0**	**90.0**	**30.0**	**90.0**	**90.0**	**30.0**	**90.0**	**90.0**	**30.0**	**90.0**	**90.0**
T50*	**193.7**	***232.0***	**193.7**	**218.2**	***232.0***	**193.7**	***232.0***	***230.5***	**193.7**	**204.9**	**229.6**
T90*	**297.6**	***335.0***	**297.6**	**338.5**	***335.0***	**297.6**	***335.0***	***335.0***	**297.6**	**304.4**	**347.6**
E200	**53.0**	**35.4**	**53.0**	**41.0**	**35.4**	**53.0**	**35.4**	**37.0**	**53.0**	**47.5**	**35.4**
E300	**90.0**	**79.0**	**90.0**	**81.0**	**79.0**	**90.0**	**79.0**	**79.0**	**90.0**	**88.5**	**79.0**
Energy Den. (MMbtu/b)	**5.07**	**5.30**	**5.08**	**5.28**	**5.28**	**5.08**	**5.30**	**5.27**	**5.08**	**5.21**	**5.28**
Composition (vol %)	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
C4s:	**2.2**	**9.3**	**2.0**	**3.5**	**8.6**	**1.7**	**4.3**	**9.5**	**2.0**	**2.8**	**8.8**
Butenes											
I-Butane				**0.7**	**1.3**	**0.2**	**3.7**	**0.1**			
N-Butane	**2.2**	**9.3**	**2.0**	**2.9**	**7.2**	**1.5**	**0.6**	**9.4**	**2.0**	**2.8**	**8.8**
C5s & Isomerate	2.7		2.5			3.2			3.5		
Natural Gas Liquids											
Naphtha:	10.9	6.6	10.3	4.7	6.8	11.5	6.7	0.2	9.8	0.7	6.1
C5 - 160	5.6		6.7	2.0		7.3			7.0		
Coker Naphtha											
160 - 175											
160 - 250	4.3	6.6	3.6	2.7	6.8	4.2	6.7	0.2	2.8	0.7	6.1
Alkylate	17.8	2.3	18.7	3.3	8.2	19.4	6.8	1.2	19.2	2.4	6.6
Poly Gas											
Hydrocrackate	14.7	0.0	14.4	12.8	2.3	15.0	3.4	1.4	16.1	16.6	3.5
FCC Gasoline:	20.9	59.3	21.4	43.6	54.2	19.9	48.3	64.1	20.1	55.2	55.6
Full Range	1.3	10.0	2.5	21.9	14.9	1.0	23.5	17.9	3.3	17.4	12.5
Light	4.0	11.5	4.6	5.7	7.3	4.5	8.3	9.7	4.8	4.6	6.9
Medium	6.3	23.6	4.6	12.1	16.6	6.1	5.1	17.1	3.6	18.4	20.3
Medium - Desulf.	4.0		4.9	3.7		1.1	8.5	20.5	3.8	11.2	
Heavy - Desulf.	5.3	14.3	4.9	2.2	15.4	7.2		2.9	4.7	3.6	16.0
Reformate:	19.8	22.0	19.7	29.4	19.9	19.4	30.4	23.6	19.3	19.8	19.4
Light Ref.	5.6		6.2	3.3	1.7	6.1	0.8	2.9	5.0	19.8	2.0
Heavy Ref.	14.2	22.0	13.4	26.1	18.2	13.3	29.6	20.7	14.2		17.4
Oxygenate	11.0		9.9			9.9			9.9	2.5	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Exhibit E-2.3: West Notional Refinery -- Changes in Refining Cost and Revenue, by Fuel Formulation Option

Measure	Fuel Formulation Option						
	Federal RFG			California		Low	10% VOC
	Phase 1	Phase1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Investment ($MM)	-0.2	-0.2	0.5	1.4	-0.2	0	0.3
Cost ($M/d)							
Input cost	14.6	16.1	24.5	30.1	15.9	2.0	38.4
Variable cost	-1.4	-1.3	-0.9	-1.1	0.1	0.1	-0.3
Capital recovery	-0.2	-0.2	0.4	2.6	-0.2	0.0	0.6
Product revenue ($M/d)	-0.4	-1.5	-8.8	8.4	-12.0	-1.4	-22.7
Net Cost ($M/d)	12.6	13.1	15.2	40.0	3.8	0.7	16.0

Exhibit E-2.4: West Notional Refinery: Modeling Results -- Changes in Crude Oil Inputs, Other Inputs, and Refined Product Outputs
(M barrels/day)

Inputs/ Outputs	Price ($/bbl)	Fuel Formulation Option							
		Current	Federal RFG Phase 1	Federal RFG Phase1/7.0 RVP	Federal RFG Phase 2	California RFG	GAPEP	Low RVP	10% VOC Reduction
Crude Oil		150.5	-1.3	-1.2	-0.8	-2.1	0.4	0.1	0.4
Domestic Composite	20	66.0	-	-	-	-	-	-	-
Foreign Composite	20	13.0	-	-	-	-	-	-	-
Alaskan North Slope	20	71.5	-1.3	-1.2	-0.8	-2.1	0.4	0.1	0.4
Other Inputs		14.9	1.0	1.0	1.0	1.8	0.2	0.0	0.8
Isobutane	18	1.0	-	-	-	-	-	-	-
Natural Gas Liquids	-	1.3	-	-	-	-	-	-	-
Alkylate	-	2.0	-	-	-	-	-	-	-
Naphtha	-	1.0	-	-	-	-	-	-	-
Heavy Gas Oil	-	3.0	-	-	-	-	-	-	-
MTBE	39.9	6.3	1.0	1.0	1.0	1.8	0.2	-	0.8
Methanol	23.1	0.3	-	-	-	-	-	-	-
Refined Products		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.62	0.08	[illegible]
Heavy Reformate	25	0.0	-	-	0.46	0.09	0.37	-	0.90
Propane	20	4.7	0.03	0.09	-0.13	-0.53	0.14	0.07	0.01
Butane	17	0.0	-	-	-	-	-	-	-
California RFG	-	72.0	-	-	-	9.00	-	-	-
Conventional Gasoline	-	9.0	-	-	-	-	-	-	-
Maricopa Co. Gasoline	-	9.0	-	-	-	-9.00	-	-	-
Jet Fuel	-	22.0	-	-	-	-	-	-	-
Diesel Fuel	-	23.0	-	-	-	-	-	-	-
Distillate - High Sulfur	-	8.0	-	-	-	-	-	-	-
Resid - Low Sulfur	15	0.1	-	-	-	-	-	-	-
Resid - High Sulfur	13	1.0	-	-	-	-	-	-	-
Asphalt	12	2.0	-	-	-	-	-	-	-
Coke	0.8	10.3	-0.06	-0.06	0.02	0.43	0.11	0.01	0.34
Sulfur	27	0.4	-0.00	-0.00	-0.00	-0.01	-0.00	0.00	-0.00

Exhibit E-3.1: Northwest Notional Refinery: Modeling Results -- Crude Oil Inputs, Process Unit Utilization, Additions, and Operations, by Fuel Formulation Option

Refininig Processes	Notional Refinery Capacity	Current	Fuel Formulation Option: Federal RFG Phase 1	Federal RFG Phase 1/7.8 RVP	Federal RFG Phase 2	California RFG	GAPEP	Low RVP	10% VOC Reduction
Crude Oil Input		149.4	148.2	148.3	148.3	147.7	149.7	149.8	149.1
Existing Capacity (M b/d):									
Fluid Cat Cracker	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5
Hydrocracker - Gas Oil. Feed	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
Coking - Delayed	25.0	20.6	19.4	19.5	19.5	19.6	21.0	21.2	20.3
Alkylation	*7.0*	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Cat. Polymerization	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Reforming (< 150 psi)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Reforming (150-350 psi)	8.7	6.6	5.2	5.6	5.5	4.3	7.1	7.0	6.0
Distillate Desulfurization	*23.5*	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5
Naphtha Desulfurization	open	0.0	1.0	1.0	1.0	1.0	0.9	0.3	1.0
Reformer Feed Desulfurization	33.3	26.8	25.2	25.6	25.5	24.8	26.7	26.7	25.5
Light Naphtha Splitting	*2.8*	2.8	2.8	2.8	2.8	2.8	2.4	2.7	2.2
C4 Isomerization	1.0	1.0	0.7		0.2	1.0	0.2	1.0	1.0
Debutanization	*7.0*	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Solvent Deasphalting	6.3	1.8	3.2	3.2	3.2	2.8	1.4	1.2	2.1
Hydrogen Plant (Scfd)	*1.34*	1.37	1.38	1.38	1.38	1.38	1.38	1.38	1.38
New Capacity (M b/d):									
Debutanization							0.1	0.3	0.2
Operating Indices:									
FCC Conversion (vol %)		77.2	76.2	76.3	76.3	76.2	77.3	77.3	77.2
Reformer Severity (RON)		101.5	101.9	101.9	101.9	101.7	101.7	101.8	102.1
Charge Rates (M b/d):									
Fluid Cat Cracker		31.5	31.6	31.6	31.6	31.2	31.5	31.5	31.5
Reformer (< 150 psi)		22.6	22.2	22.2	22.2	22.6	22.2	22.2	22.0
Reformer (150-350 psi)		5.3	4.2	4.5	4.4	3.5	5.7	5.6	4.8

Note: Italics indicates ARMS added some or all of capacity in the base case.

Exhibit E-3.2: **Northwest Notional Refinery: Modeling Results -- Gasoline Properties and Composition, by Fuel Formulation Option**

Property & Composition	Anti-Dumping Baseline	Fuel Formulation Option											
		Current		Phase 1 RFG			Phase 1 RFG, 7.0 RVP			Phase 2 RFG			
		Conv.	Cal. RFG	Conv.	Cal. RFG	Maricopa	Conv.	Cal. RFG	Maricopa	Conv.	Cal. RFG	Maricopa	
Property													
RVP (psi)	7.8	7.8	6.7	7.8	6.7	7.1	7.8	6.7	6.7	7.8	6.7	6.8	
Oxygen (wt%)	0.0	0.0	1.8	0.0	1.8	2.1	0.0	1.8	2.1	0.0	1.8	2.1	
Aromatics (vol%)	34.7	38.0	18.5	37.8	20.0	24.2	38.0	22.0	23.4	38.0	22.0	22.9	
Benzene (vol%)	2.66	2.50	0.80	2.50	0.80	0.95	2.50	0.80	0.95	2.50	0.80	0.95	
Olefins (vol%)	9.9	10.7	2.8	10.7	1.1	7.8	10.7	0.3	8.5	10.5	4.0	8.0	
Sulfur (ppm)	385.1	422.4	14.4	398.4	30.0	250.0	408.2	30.0	179.4	422.0	30.0	74.2	
T50**	206.0	206.6	196.7	206.6	187.7	188.5	206.6	186.6	191.0	206.6	191.3	187.8	
T90**	323.8	333.5	284.0	333.5	284.0	301.3	333.5	284.0	308.8	333.5	284.0	307.0	
E200	46.6	46.3	51.1	46.3	55.6	55.2	46.3	56.1	53.9	46.3	53.8	55.5	
E300	84.2	82.1	93.0	82.1	93.0	89.2	82.1	93.0	87.5	82.1	93.0	87.9	
Energy Den. (MMbtu/b)	5.25	5.27	5.08	5.27	5.07	5.07	5.27	5.09	5.07	5.27	5.09	5.07	
Composition (vol %)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
C4s:	4.7	4.7	2.4	4.8	1.3	3.0	5.0	1.3	1.3	5.0	1.3	1.9	
Butenes	1.2	1.1	2.4	1.2			1.2			1.1	0.9		
I-Butane	1.8	1.9		1.1	1.3	2.4		1.1	0.8	0.4	0.4	0.3	
N-Butane	1.7	1.7		2.4		0.5	3.8	0.2	0.5	3.4		1.5	
C5s & Isomerate													
Raffinate													
Naphtha:	13.5	14.8	16.3	13.6	24.3	18.7	12.9	23.7	23.7	12.8	24.8	24.9	
C5 - 160	12.0	13.0	4.6	12.6	24.3	18.7	12.2	23.7	20.5	12.5	13.7	24.9	
Coker Naphtha	1.5	1.7											
160 - 175			11.7	0.9			0.8		0.9	0.1	10.2		
160 - 250				0.2					2.3	0.2	0.9		
Alkylate	10.1	3.3	43.7	4.9	21.9	3.0	3.1	16.9	19.8	4.0	32.5	4.2	
Poly Gas.	1.2	1.3		1.1	0.8	2.5	0.9		4.5	0.4	2.8	7.1	
Hydrocrackate	11.1	10.5	5.5	9.4	17.8	22.1	11.3	19.6	2.0	10.4		21.6	
FCC Gasoline:	27.0	30.1	0.0	31.6	0.0	17.9	32.4	0.0	12.3	33.5	0.1	3.7	
Full Range	27.0	30.1		31.6		17.9	32.4	0.0	12.3	33.5	0.1	3.7	
Light													
Medium													
Medium - Desulf.													
Heavy - Desulf.													
Reformate:	32.3	35.4	24.3	34.5	24.0	21.4	34.3	26.5	24.8	34.0	28.7	25.3	
Light Ref.	13.9	14.0	12.3	14.7	9.6	6.7	14.5	10.9	6.5	14.8	16.9	1.3	
Heavy Ref.	18.4	21.4	12.1	19.9	14.4	14.8	19.8	15.6	18.3	19.2	11.8	23.9	
Oxygenate			9.9		9.9	11.5		9.9	11.5		9.9	11.5	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

** Based on EPA formulas:
T50 = (147.91 - E200) / 0.49
T90 = (155.47 - E300) / 0.22

Exhibit E-3.2: Northwest Notional Refinery: Modeling Results -- Gasoline Properties and Composition, by Fuel Formulation Option

Property & Composition	Fuel Formulation Option										
	California RFG		GAPEP			Low RVP			10% VOC Reduction		
	Conv.	Cal. RFG	Conv.	Cal. RFG	Maricopa	Conv.	Cal. RFG	Maricopa	Conv.	Cal. RFG	Maricopa
Property											
RVP (psi)	7.8	6.7	7.8	6.7	6.7	7.8	6.7	6.2	7.8	6.7	6.5
Oxygen (wt%)	0.0	2.2	0.0	1.8	0.0	0.0	1.8	0.0	0.0	1.8	0.9
Aromatics (vol%)	38.0	19.6	38.0	22.0	35.9	38.0	22.0	36.1	38.0	17.9	30.0
Benzene (vol%)	2.50	0.80	2.50	0.80	2.60	2.50	0.80	2.50	2.50	0.80	2.50
Olefins (vol%)	10.7	4.0	10.2	4.0	10.0	10.7	4.0	9.0	10.7	4.0	4.7
Sulfur (ppm)	422.0	30.0	422.0	30.0	116.0	422.0	30.0	339.4	406.7	25.0	200.0
T50**	206.6	183.9	206.4	199.0	206.7	206.6	195.8	208.0	206.6	199.0	192.8
T90**	333.5	284.0	332.2	284.0	338.5	333.5	284.0	330.9	333.5	284.0	304.9
E200	46.3	57.4	46.4	50.0	46.2	46.3	51.6	45.6	46.3	50.0	53.0
E300	82.1	93.0	82.4	93.0	81.0	82.1	93.0	82.7	82.1	93.0	88.4
Energy Den. (MMbtu/b)	5.26	5.05	5.27	5.08	5.26	5.27	5.08	5.28	5.27	5.07	5.17
Composition (vol %)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	4.8	1.3	5.1	2.1	1.3	4.8	1.3	1.3	4.7	2.8	1.5
Butenes	1.1	0.3	1.4			1.3		0.8	1.3		0.2
I-Butane	2.0	0.1	0.5	2.1	0.6	2.2			1.8	2.8	1.3
N-Butane	1.8	0.9	3.2		0.7	1.3	1.3	0.5	1.6		
C5s & Isomerate											
Raffinate											
Naphtha:	12.6	25.4	15.1	16.5	10.9	13.1	19.5	26.1	15.2	13.1	11.3
C5 - 160	12.5	21.2	14.5	16.2	8.6	11.9	16.8	19.2	14.5	13.1	11.3
Coker Naphtha				0.2	1.5	0.6	0.2	6.9			
160 - 175	0.1	4.2	0.6		0.8	0.7	2.6		0.7		
160 - 250											
Alkylate	3.3	17.8	4.1	28.1	6.1	2.4	34.7	14.7	4.7	24.1	3.7
Poly Gas	0.8	3.6	0.2	3.8	7.7	1.1	3.7	1.0	1.1	3.9	1.1
Hydrocrackate	11.2	16.3	8.7	11.8	23.2	12.4	1.2	2.0	8.0	24.9	32.4
FCC Gasoline:	33.6	0.0	33.5	0.0	5.0	32.4	0.0	13.0	32.2	0.0	14.4
Full Range	33.6		33.5		5.0	32.4		13.0	32.2		14.4
Light											
Medium											
Medium - Desulf.											
Heavy - Desulf.											
Reformate:	33.5	23.6	33.4	27.9	45.9	33.7	29.7	41.9	34.1	21.2	30.5
Light Ref.	14.4	9.2	14.5	15.6	8.4	13.9	18.0	12.6	14.5	7.9	11.9
Heavy Ref.	19.1	14.3	18.9	12.4	37.4	19.9	11.7	29.2	19.6	13.4	18.6
Oxygenate	0.1	12.1		9.9			9.9			9.9	5.0
Gasoline Vol. (M b/d)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Exhibit E-3.3: Northwest Notional Refinery -- Changes in Refining Cost and Revenue, by Fuel Formulation Option

	Fuel Formulation Option						
	Federal RFG			California		Low	10% VOC
ARMS Results	Phase 1	Phase 1/7.0 RVP	Phase 2	RFG	GAPEP	RVP	Reduction
Investment ($MM)	-	-	-	-	-	-	-
Cost ($M/d)							
Input cost	2.5	4.0	3.7	6.0	-0.7	2.4	2.5
Variable cost	-0.9	-1.1	-1.0	-1.2	-0.4	0.0	-0.5
Capital recovery	-	-	-	-	-	-	-
Product Revenue ($M/d)	-7.3	-6.7	-6.8	-9.3	-1.5	1.6	-1.6
Net Cost ($M/d)	8.9	9.6	9.5	14.1	0.4	0.8	3.6

Exhibit E-3.4: Northwest Notional Refinery: Modeling Results -- Changes in Crude Oil Inputs, Other Inputs, and Refined Product Outputs
(M barrels/day)

Inputs/ Outputs	Price ($/bbl)	Current	Fuel Formulation Option: Federal RFG Phase 1	Federal RFG Phase 1/7.0 RVP	Federal RFG Phase 2	California RFG	GAPEP	Low RVP	10% VOC Reduction
Crude Oil		149.4	-1.2	-1.1	-1.1	-1.7	0.3	-0.3	0.4
Alaskan North Slope	20	118.4	-1.2	-1.1	-1.1	-1.7	0.3	-0.3	0.4
Canadian Peace River	20	31.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Inputs		0.4	0.8	0.8	0.8	1.2	0.0	0.4	0.0
MTBE	39.9	0.4	0.8	0.8	0.8	1.2	0.0	0.4	0.0
Refined Products		153.1	-0.4	-0.2	-0.4	-0.4	0.3	0.2	0.5
Alkylate	-	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	20	4.0	-0.1	-0.1	-0.1	-0.1	0.0	-0.0	0.1
Butane	17	1.1	-0.1	-0.1	-0.1	-0.2	0.1	0.2	0.3
California RFG	-	4.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0
Conventional Gasoline	-	60.0	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0
Maricopa Co. Gasoline	-	0.0	7.0	7.0	7.0	0.0	7.0	7.0	7.0
Jet Fuel	-	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diesel Fuel	-	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distillate - High Sulfur	-	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas Oils	-	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Resid - High Sulfur	13	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coke	0.8	4.8	-0.3	-0.2	-0.3	-0.2	0.1	-0.1	0.2
SLP	27	0.13	-0.00	0.13	-0.00	0.13	0.00	0.13	0.00

APPENDIX F

DETAILED RESULTS OF THE EMISSIONS ANALYSIS

Appendix F

Detailed Presentation of Emission Benefits

This section presents the detailed emission benefits developed using the methodology described in Chapter 5 and the fuel compositions described in Chapter 6.

F.1 Exhaust VOC, NOx, and Toxics Emission Impacts

We estimated the exhaust emission impacts of each of the fuels described in Chapter 6 using both the Complex Model and the Tech 3 and Tech 4 portions of the Predictive Model. The effect of sulfur was removed for NOx emissions for pre-1981 vehicles and for all emissions from non-road engines.

We estimated the difference in exhaust emissions between 1996 Maricopa County gasoline and the Clean Air Act Baseline (CAAB) gasoline, as well as the difference between the exhaust emissions associated with all of the fuel options and 1996 Maricopa County gasoline. The models were applied to fuels produced in East and West refineries separately and a volume-weighted average of the two emission impacts was then determined. The weighting was 27.7% East fuel and 72.3% West fuel. **Exhibits F.1** and **F.2** present the exhaust emission impacts using the Predictive and Complex Models, respectively, for each vintage group of vehicles.

Exhibit F.1: On-Road Emission Impacts By Model Year Grouping: Predictive Model								
	1995 Phoenix Base*	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
Pre-1981 Model Year On-Road Vehicles (Tech3 Predictive Model w/o Sulfur Effect for NOx)								
NOx	1.9%	0.9%	1.1%	-1.3%	0.4%	0.6%	-7.7%	-1.0%
Exhaust VOC	4.2%	-9.8%	-11.1%	-12.2%	-3.5%	-0.2%	-14.3%	-10.3%
Exhaust benzene	-10.3%	-20.5%	-20.3%	-26.1%	0.1%	-1.4%	-40.7%	-4.3%
Butadiene	5.9%	-0.5%	0.1%	-11.1%	0.4%	8.2%	-35.6%	-17.5%
Formaldehyde	23.7%	35.9%	35.6%	46.2%	9.1%	-0.4%	75.5%	16.7%
Acetaldehyde	-3.5%	4.7%	4.5%	8.7%	0.0%	-0.6%	17.5%	5.6%
1981-85 Model Year On-Road Vehicles (Tech3 Predictive Model)								
NOx	-0.5%	0.5%	0.7%	-2.0%	-0.6%	0.6%	-9.4%	-1.2%
Exhaust VOC	4.2%	-9.8%	-11.1%	-12.2%	-3.5%	-0.2%	-14.3%	-10.3%
Exhaust benzene	-10.3%	-20.5%	-20.3%	-26.1%	0.1%	-1.4%	-40.7%	-4.3%
Butadiene	5.9%	-0.5%	0.1%	-11.1%	0.4%	8.2%	-35.6%	-17.5%
Formaldehyde	23.7%	35.9%	35.6%	46.2%	9.1%	-0.4%	75.5%	16.7%
Acetaldehyde	-3.5%	4.7%	4.5%	8.7%	0.0%	-0.6%	17.5%	5.6%
1986 and Later Model Year On-Road Vehicles (Tech4 Predictive Model)								
NOx	-7.2%	-1.7%	-1.7%	-3.3%	-3.6%	0.1%	-9.3%	-1.2%
Exhaust VOC	1.3%	-10.6%	-12.0%	-16.6%	-8.3%	2.0%	-25.8%	-16.2%
Exhaust benzene	-12.4%	-20.6%	-21.2%	-29.6%	-6.4%	-1.4%	-50.5%	-11.1%
Butadiene	-1.9%	-4.6%	-5.5%	-12.0%	-5.6%	3.9%	-34.7%	-15.6%
Formaldehyde	4.4%	15.5%	15.7%	14.6%	2.0%	3.9%	15.3%	-1.5%
Acetaldehyde	3.0%	6.2%	4.6%	3.0%	-4.6%	2.3%	-2.8%	-10.6%

* Relative to Clean Air Act Baseline gasoline. All other fuel impacts are relative to Phoenix base gasoline.

Exhibit F.2: On-Road Emission Impacts By Model Year Grouping: Complex Model								
	1995 Phoenix Base *	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
Pre-1981 Model Year Vehicles (Complex Model w/o Sulfur Effect for NOx)								
NOx	-0.1%	0.5%	0.4%	-0.5%	1.1%	0.5%	-3.7%	0.4%
Exhaust VOC	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
Exhaust benzene	-8.3%	-23.7%	-23.8%	-28.4%	1.6%	-7.2%	-40.6%	4.1%
Butadiene	7.6%	-12.3%	-13.4%	-18.0%	-1.2%	0.9%	-40.2%	-16.8%
Formaldehyde	-0.9%	9.6%	9.7%	10.6%	-4.3%	4.3%	24.6%	-6.3%
Acetaldehyde	-3.0%	-8.0%	-8.5%	-11.1%	-5.4%	-4.4%	-14.8%	-11.3%
POM	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
1981-85 Model Year Vehicles (Complex Model)								
NOx	-5.8%	-0.5%	-0.4%	-2.3%	-1.7%	0.1%	-9.3%	-0.1%
Exhaust VOC	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
Exhaust benzene	-8.3%	-23.7%	-23.8%	-28.4%	1.6%	-7.2%	-40.6%	4.1%
Butadiene	7.6%	-12.3%	-13.4%	-18.0%	-1.2%	0.9%	-40.2%	-16.8%
Formaldehyde	-0.9%	9.6%	9.7%	10.6%	-4.3%	4.3%	24.6%	-6.3%
Acetaldehyde	-3.0%	-8.0%	-8.5%	-11.1%	-5.4%	-4.4%	-14.8%	-11.3%
POM	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
1986 and Later Model Year Vehicles (Complex Model)								
NOx	-5.8%	-0.5%	-0.4%	-2.3%	-1.7%	0.1%	-9.3%	-0.1%
Exhaust VOC	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
Exhaust benzene	-8.3%	-23.7%	-23.8%	-28.4%	1.6%	-7.2%	-40.6%	4.1%
Butadiene	7.6%	-12.3%	-13.4%	-18.0%	-1.2%	0.9%	-40.2%	-16.8%
Formaldehyde	-0.9%	9.6%	9.7%	10.6%	-4.3%	4.3%	24.6%	-6.3%
Acetaldehyde	-3.0%	-8.0%	-8.5%	-11.1%	-5.4%	-4.4%	-14.8%	-11.3%
POM	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%

* Relative to Clean Air Act Baseline gasoline. All other fuel impacts are relative to Phoenix base gasoline.

These changes in exhaust emissions were then combined to project an overall percentage change in fleet-wide exhaust emissions for on-road vehicles in 1999 and 2010. One set of projections utilizes the Complex Model for 1986 and later vehicles, while the other utilizes the Tech 4 model. These are shown in **Exhibits F.3** and **F.4**. Also shown are the projected impacts on exhaust VOC and NOx emissions from non-road engines. These latter impacts did not involve any weighting of engine vintages.

Exhibit F.3: Fleet-Wide Emission Impacts: Predictive Model								
	1995 Phoenix Base *	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
On-Road Vehicles: Calendar Year 1999								
NOx	-5.6%	-1.2%	-1.2%	-2.9%	-2.8%	0.2%	-9.2%	-1.2%
Exhaust VOC	2.2%	-10.4%	-11.7%	-15.2%	-6.8%	1.3%	-22.3%	-14.4%
Exhaust benzene	-11.7%	-20.6%	-20.9%	-28.5%	-4.4%	-1.4%	-47.5%	-9.0%
Butadiene	0.5%	-3.4%	-3.8%	-11.7%	-3.8%	5.2%	-35.0%	-16.2%
Formaldehyde	10.3%	21.8%	21.8%	24.3%	4.2%	2.5%	33.9%	4.1%
Acetaldehyde	1.0%	5.8%	4.6%	4.8%	-3.2%	1.4%	3.5%	-5.6%
On-Road Vehicles: Calendar Year 2010								
NOx	-7.2%	-1.7%	-1.7%	-3.3%	-3.6%	0.1%	-9.3%	-1.2%
Exhaust VOC	1.3%	-10.6%	-12.0%	-16.6%	-8.3%	2.0%	-25.8%	-16.2%
Exhaust benzene	-12.4%	-20.6%	-21.2%	-29.6%	-6.4%	-1.4%	-50.5%	-11.1%
Butadiene	-1.9%	-4.6%	-5.5%	-12.0%	-5.6%	3.9%	-34.7%	-15.6%
Formaldehyde	4.4%	15.5%	15.7%	14.6%	2.0%	3.9%	15.3%	-1.5%
Acetaldehyde	3.0%	6.2%	4.6%	3.0%	-4.6%	2.3%	-2.8%	-10.6%
Non-Road Engines								
NOx	1.9%	0.9%	1.1%	-1.3%	0.4%	0.6%	-7.7%	-1.0%
Exhaust VOC	2.8%	-9.9%	-11.1%	-10.8%	-3.3%	0.1%	-8.9%	-9.6%

* Relative to Clean Air Act Baseline gasoline. All other fuel impacts are relative to Phoenix base gasoline.

Exhibit F.4: Fleet-Wide Emission Impacts: Complex Model								
	1995 Phoenix Base *	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
On-Road Vehicles: Calendar Year 1999								
NOx	-5.2%	-0.4%	-0.3%	-2.1%	-1.4%	0.2%	-8.7%	0.0%
Exhaust VOC	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
Exhaust benzene	-8.3%	-23.7%	-23.8%	-28.4%	1.6%	-7.2%	-40.6%	4.1%
Butadiene	7.6%	-12.3%	-13.4%	-18.0%	-1.2%	0.9%	-40.2%	-16.8%
Formaldehyde	-0.9%	9.6%	9.7%	10.6%	-4.3%	4.3%	24.6%	-6.3%
Acetaldehyde	-3.0%	-8.0%	-8.5%	-11.1%	-5.4%	-4.4%	-14.8%	-11.3%
On-Road Vehicles: Calendar Year 2010								
NOx	-5.8%	-0.5%	-0.4%	-2.3%	-1.7%	0.1%	-9.3%	-0.1%
Exhaust VOC	2.0%	-8.3%	-10.2%	-13.8%	-6.1%	-2.4%	-16.6%	-12.4%
Exhaust benzene	-8.3%	-23.7%	-23.8%	-28.4%	1.6%	-7.2%	-40.6%	4.1%
Butadiene	7.6%	-12.3%	-13.4%	-18.0%	-1.2%	0.9%	-40.2%	-16.8%
Formaldehyde	-0.9%	9.6%	9.7%	10.6%	-4.3%	4.3%	24.6%	-6.3%
Acetaldehyde	-3.0%	-8.0%	-8.5%	-11.1%	-5.4%	-4.4%	-14.8%	-11.3%
Non-Road Engines								
NOx	-0.1%	0.5%	0.4%	-0.5%	1.1%	0.5%	-3.7%	0.4%
Exhaust VOC	-0.4%	-5.0%	-7.6%	-10.8%	-2.4%	0.1%	-12.4%	-10.0%

* Relative to Clean Air Act Baseline gasoline. All other fuel impacts are relative to Phoenix base gasoline.

C.2 Non-Exhaust VOC, Non-Exhaust Benzene and CO Emissions

MOBILE5a was utilized in conjunction with baseline VOC emission inventories developed for the UAM modeling to estimate non-exhaust VOC emissions under each fuel option. Non-exhaust VOC emissions are solely a function of fuel RVP. Non-exhaust VOC emission factors are shown in Table F.5.

Table F.5 Non-Exhaust VOC Emissions (g/mi)		
RVP	1999	2010
7.1	0.665	0.364
7.0	0.656	0.358
6.9	0.646	0.352
6.8	0.637	0.346
6.7	0.628	0.340
6.6	0.620	0.334
6.5	0.611	0.328
6.4	0.611	0.328
6.3	0.611	0.328
6.2	0.611	0.328

Exhibit F.6 shows the effect of each fuel option on non-exhaust VOC emissions in percentage terms. Exhibit F.6 also shows similar figures for the benzene fraction of non-exhaust VOC emissions and CO emissions. Both sets of figures were developed using the Complex Model. The on-road CO emission impacts are weighted by model year grouping.

Exhibit F.6: On-Road CO, Non-Exhaust VOC and Non-Exhaust Benzene Emission Impacts: Complex Model								
	1995 Phoenix Base *	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
Onroad CO	-3.2%	-12.2%	-11.7%	-14.5%	-5.5%	-2.0%	-20.8%	-4.0%
Nonroad CO	2.7%	-7.3%	-10.6%	-12.3%	-2.1%	-1.9%	-15.7%	-3.1%
Non-Exhaust VOC: 1999	-4.2%	5.8%	0.0%	-1.4%	0.0%	-2.7%	0.0%	-2.7%
Non-Exhaust VOC: 2010	-5.1%	7.3%	0.0%	-1.7%	0.0%	-3.4%	0.0%	-3.4%
Evap Benzene (% of Evap VOC)	-14.8%	-31.0%	-28.2%	-27.6%	11.5%	-0.8%	-45.5%	11.4%

* Relative to Clean Air Act Baseline gasoline. All other fuel impacts are relative to Phoenix base gasoline.

C.3 Total VOC and NOx Emissions

The above changes in exhaust and non-exhaust emissions were combined to estimate the change in total VOC and NOx emissions for on-road and non-road sources. These are shown in **Exhibit F.7**.

Exhibit F.7: VOC and NOx Emission Impacts in Maricopa County (% of baseline emissions)							
	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
Calendar Year 1999							
Predictive Model							
Onroad VOC	-3.6%	-6.8%	-9.4%	-3.9%	-0.4%	-12.9%	-9.5%
Nonroad VOC	-7.9%	-9.7%	-9.6%	-2.9%	-0.2%	-7.7%	-8.7%
Total VOC	-5.1%	-7.8%	-9.5%	-3.6%	-0.3%	-11.1%	-9.2%
Onroad NOx	-1.2%	-1.2%	-2.9%	-2.8%	0.2%	-9.2%	-1.2%
Nonroad NOx	0.9%	1.1%	-1.3%	0.4%	0.6%	-7.7%	-1.0%
Total NOx	-1.2%	-1.1%	-2.9%	-2.7%	0.2%	-9.2%	-1.2%
Complex Model							
Onroad VOC	-2.3%	-5.9%	-8.6%	-3.5%	-2.5%	-9.6%	-8.3%
Nonroad VOC	-3.6%	-6.6%	-9.6%	-2.1%	-0.3%	-10.8%	-9.1%
Total VOC	-2.8%	-6.2%	-8.9%	-3.0%	-1.7%	-10.1%	-8.6%
Onroad NOx	-0.4%	-0.3%	-2.1%	-1.4%	0.2%	-8.7%	0.0%
Nonroad NOx	0.5%	0.4%	-0.5%	1.1%	0.5%	-3.7%	0.4%
Total NOx	-0.4%	-0.3%	-2.1%	-1.3%	0.2%	-8.5%	0.0%
Calendar Year 2010							
Predictive Model							
Onroad VOC	-4.0%	-7.5%	-11.1%	-5.2%	0.0%	-16.3%	-11.5%
Nonroad VOC	-4.8%	-7.8%	-8.1%	-2.3%	-0.9%	-6.2%	-7.7%
Total VOC	-4.2%	-7.6%	-10.2%	-4.4%	-0.3%	-13.4%	-10.4%
Onroad NOx	-1.7%	-1.7%	-3.3%	-3.6%	0.1%	-9.3%	-1.2%
Nonroad NOx	0.9%	1.1%	-1.3%	0.4%	0.6%	-7.7%	-1.0%
Total NOx	-1.6%	-1.6%	-3.2%	-3.4%	0.1%	-9.3%	-1.2%
Complex Model							
Onroad VOC	-2.5%	-6.5%	-9.3%	-3.8%	-2.7%	-10.5%	-9.1%
Nonroad VOC	-1.3%	-5.3%	-8.1%	-1.6%	-0.9%	-8.7%	-8.0%
Total VOC	-2.2%	-6.1%	-9.0%	-3.2%	-2.2%	-10.0%	-8.8%
Onroad NOx	-0.5%	-0.4%	-2.3%	-1.7%	0.1%	-9.3%	-0.1%
Nonroad NOx	0.5%	0.4%	-0.5%	1.1%	0.5%	-3.7%	0.4%
Total NOx	-0.4%	-0.3%	-2.2%	-1.6%	0.2%	-9.0%	-0.1%

C.4Particulate (PM10) Emissions

The PART5 model was used to estimate baseline PM10 emission factors. Changes in these emissions were based on the projected change in exhaust VOC emissions and the fuel sulfur content in each fuel option. The resulting PM10 emission factors are shown in **Exhibit F.8**.

Exhibit F.8: Particulate Emission Factors: PART5 (g/mi)								
	1995 Phoenix Base*	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
Predictive Model								
On-Road Vehicles: Calendar Year 1999								
Direct Sulfate	0.004	0.003	0.003	0.003	0.002	0.004	0.001	0.004
Direct Carbonaceous	0.009	0.008	0.008	0.008	0.008	0.009	0.007	0.008
Total Exhaust	0.013	0.011	0.011	0.010	0.011	0.013	0.008	0.011
Indirect Sulfate	0.012	0.010	0.010	0.008	0.007	0.012	0.002	0.011
Total PM10	0.025	0.021	0.021	0.018	0.018	0.025	0.010	0.022
On-Road Vehicles: Calendar Year 2010								
Direct Sulfate	0.004	0.003	0.003	0.003	0.002	0.004	0.001	0.004
Direct Carbonaceous	0.006	0.005	0.005	0.005	0.005	0.006	0.004	0.005
Total Exhaust	0.010	0.008	0.008	0.007	0.007	0.010	0.005	0.008
Indirect Sulfate	0.012	0.010	0.010	0.008	0.007	0.012	0.002	0.011
Total PM10	0.021	0.018	0.018	0.015	0.014	0.021	0.007	0.019
Complex Model								
On-Road Vehicles: Calendar Year 1999								
Direct Sulfate	0.004	0.003	0.003	0.003	0.002	0.004	0.001	0.004
Direct Carbonaceous	0.009	0.008	0.008	0.008	0.009	0.009	0.008	0.008
Total Exhaust	0.013	0.012	0.011	0.011	0.011	0.013	0.008	0.012
Indirect Sulfate	0.012	0.010	0.010	0.008	0.007	0.012	0.002	0.011
Total PM10	0.025	0.022	0.021	0.018	0.018	0.025	0.010	0.022
On-Road Vehicles: Calendar Year 2010								
Direct Sulfate	0.004	0.003	0.003	0.003	0.002	0.004	0.001	0.004
Direct Carbonaceous	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Total Exhaust	0.010	0.008	0.008	0.007	0.007	0.009	0.005	0.008
Indirect Sulfate	0.012	0.010	0.010	0.008	0.007	0.012	0.002	0.011
Total PM10	0.021	0.018	0.018	0.015	0.014	0.021	0.007	0.019

* Relative to Clean Air Act Baseline gasoline. All other fuel impacts are relative to Phoenix base gasoline.

Exhibit F.9 shows the change in exhaust PM10 emissions (carbonaceous and sulfate) in percentage terms. Also shown are the directional effects of each fuel option on the amount of secondary organic aerosol likely to be formed from gaseous VOC emissions.

Exhibit F.9: Summary of PM10 Emission Impacts in Maricopa County							
	Fed RFG I	Fed RFG I w/ RVP Waiver	Fed RFG II	Task Force	Low RVP	CA RFG II	10% VOC Reduction
Direct Sulfate and Carbonaceous PM (% Change from Phoenix Base Gasoline)							
Predictive Model							
1999	-13.5%	-14.5%	-21.9%	-18.8%	-0.6%	-41.5%	-14.4%
2010	-13.7%	-14.5%	-24.1%	-23.2%	0.4%	-50.1%	-14.3%
Complex Model							
1999	-12.0%	-13.4%	-20.8%	-18.2%	-3.0%	-37.5%	-12.9%
2010	-12.8%	-13.9%	-22.9%	-22.2%	-2.5%	-45.1%	-12.5%
Indirect Carbonaceous *	<	<	<<	---	>	<<<	<
* "<" or ">" means a reduction or increase due to one fuel factor, "<<" means a reduction due to 2 fuel factors, etc.; "---" means no change							